DECISION MAKING AND UNCERTAINTY ANALYSIS IN SUCCESS OF CONSTRUCTION PROJECTS

A Dissertation

by

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ABSTRACT

This study identifies key construction cost and schedule performance determinants related to project general characteristics, specific features, and construction best practices for heavy industrial projects. This research examines the relationship between factors corresponding to each phase of a project and develops a qualitative model to help project managers and owners ascertain project success probability at the early stages of a project.

To carry out the designed research methodology, the CII-RT305 data set was used, and missing data points were generated through mean value substitution and transformed to their corresponding *z*-values. Several statistical tests including two sample t-test, Kruskal-Wallis test and chi-squared test were conducted to identify critical cost and schedule performance indicators. The results of the correlation analysis between project characteristics and phase-based project cost and schedule overrun are also presented. The outcomes of this analysis are used for the sequential variable reduction. The output of this screening phase is used as an input for stepwise data reduction in order to further decrease the number of potential indicators. Next, construction experience is used to incorporate the excluded cost and schedule performance indicators, if it is believed that the variable was excluded through the statistics. Then, the all-possible combination regression is used to finalize the phase-based cost and schedule performance indicators.

Leamer's and Sala-i-Martin Extreme Bounds Analysis (EBA) methods are used to study the robustness or fragility of the identified variables. In practice, the purpose of identifying robust cost and schedule performance indicators during engineering/design, procurement and construction phases is to guide project managers in allocating their limited human and machinery resources more effectively and efficiently.

This research contributes to the field of construction engineering and management in two major ways. First, it identifies project factors/characteristics which drive poor project cost and schedule performance during the engineering/design, procurement and construction phases. Secondly, it determines the robustness of each of these cost and schedule performance indicators during the engineering/design, procurement and construction phases, which assists project managers to allocate their resources more effectively.

For future studies, the author recommends that the coupled impact of project cost and schedule performance be studied. For this purpose, it is suggested to define the success of a project by integrating the project total cost and schedule and make a new project parameter. Categorizing the continuous data makes it possible to integrate the cost and schedule performance and develop a predictive logistic regression model to predict project success level during the conception phase.

DEDICATION

This dissertation is dedicated to my beloved parents, who instilled in me the virtues of perseverance and commitment and relentlessly encouraged me to strive for excellence. Mom and dad, thank you for all your unconditional love throughout my life. Without your support, none of my success would have been possible.

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Foremost, I would like to express my sincere gratitude to my advisor Prof. Stuart Anderson for the continuous support of my Ph.D. studies and research, for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me all the time of research and writing of this dissertation. I could not have imagined having a better advisor and mentor for my Ph.D. studies.

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Thanks also go to my friends and colleagues and Civil Engineering Department faculty and staff for making my time at Texas A&M University a great experience.

Last but not least, I would like to express my eternal gratitude to my parents for their everlasting love and support.

NOMENCLATURE

AHP	Analytic Hierarchy Process
CDF	Cumulative Density Function
CII	Construction Industry Institute
CM	Construction Management
CSF	Critical Success Factor
EBA	Extreme Bounds Analysis
PMT	Project Management Team
QA	Quality Assurance
QC	Quality Control

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The ultimate goal of every project manager is to accomplish a project successfully. However, the construction industry is dynamic in nature due to uncertainties associated with technologies, budgets, and development processes and the rather complex and uncertain nature of the construction environment challenges project managers in achieving successful construction-project outcomes. Construction projects have different sources of uncertainty originated from shortage of material and labor, unfavorable weather conditions, unstable political environments, inadequate cash reserves, possible inflationary effects on project costs, and the short-term nature of most construction projects. Despite these seemingly endless hurdles, it is nevertheless possible for a project manager to consistently achieve outstanding project results. However, by including project management input based on previous experiences and practices related to success in the execution plan, the likelihood of achieving an outstanding project cost and schedule performance can be enhanced.

One of the major issues in the construction industry is how to define and measure project success. Traditionally, time, cost and quality were considered to be the three main criteria to define project success (Oisen, 1971). However, Wright (1997) reduced the number of criteria and suggested only two parameters of time and budget could be the major determinants of a project success level.

1.1 Identified Problem

A project is considered a success if it meets the technical specifications, and if there is a high level of satisfaction concerning the project outcome among clients, completed within a stated cost or budget and getting the project into use by a target date. However, most researchers addressed the project success by considering cost, time and quality/performance (De Wit, 1988;Wright, 1997; Arditi and Gunaydin, 1997; Frimpong et al., 2003; Williams, 2003; Luu et al., 2003). Taking the view of customers into account as primary measure of success, Wright (1997) reduced the project success measures into two major parameters, time and budget.

Cost overruns and delays in construction projects are common in the construction of oil and gas industry facilities. Construction delays and overruns are often responsible for turning profitable projects into loosing ventures. The major causes of such delays and cost overrun can be identified and dealt with in a timely fashion.

Owners and contractors face numerous challenges and hurdles to complete billion dollar engineering and construction projects. Considering cost and time as customer driven criteria for project success, it is desirable to identify problems that lead to significant delays and cost overruns. Typical problems that most heavy industrial projects encounter can be summarized in the items described below (Long et al., 2004):

- Multiple change orders due to scope additions/deletions;
- Insufficient management of contractor design and construction interfaces;
- Insufficient and inexperienced owner technical personnel;
- Insufficient facilities for remotely located projects;

- Incomplete fabrication prior to shipping;
- Failure to have experienced management team.

Considering time and cost as two major indicators of project success, there are limited studies which have focused on determining the project success indicators during each of the design/engineering, procurement and construction phases. Therefore, the main aim of this study is to determine project success indicators during each of the three mentioned phases.

1.2 Research Goal and Objectives

In order to determine if a project has met its cost and schedule targets, contractors and owners compare the initial estimate of the project cost and schedule with how much actually was spent to complete the project and how long it took to execute it. The differences between the estimate and actual project cost and time are referred to as "cost performance" and "schedule performance". The lower the absolute value of these differences, the better performance a project has in terms of cost and schedule.

The overall goal of this research is to develop a decision making framework for systematic modeling and analysis of factors affecting project cost and schedule performance from owner's and contractor's perspectives. This goal is achieved through three objectives of this study, provided below:

Objective 1: Identify potential causes of delay and cost overrun in construction of heavy industrial projects during each of engineering/design, procurement and construction phases. This study seeks to find variables which could fulfill this objective at the very early stages of the project.

Objective 2: Develop a model to predict cost and schedule overruns during each single phase of design/engineering, procurement and construction. The purpose of these models is not to estimate the exact value of potential cost and schedule overruns. Rather, it is intended to guide project managers and owners to plan proactively and apply appropriate strategies if there is a high probability that the project could face cost and schedule overruns.

Objective 3: Determine how robustly each of the engineering/design, procurement and construction cost and schedule indicators are associated with the project cost and schedule performance. By identifying these robust factors, project managers could make more informed decisions regarding how to allocate their limited resources to project variables/activities so to improve project cost and schedule performance.

1.3 Research Questions and Hypothesis

Several related research questions regarding phase-based project cost and schedule performance were developed to direct the research around the purpose and objectives, including:

- What is project success and how it can be measured?
- What are the project cost and schedule performance indicators during the engineering/design, procurement and construction phases?

- Which of the identified potential cost and schedule performance indicators should be primarily focused on?
- Where should project managers and owner allocate more resources to in order to improve the probability of the project success?

Based on the research questions, two primary hypotheses were identified. These hypotheses were tested quantitatively using statistical methods based on data set used for this analysis. The proposed hypotheses were:

Hypothesis 1:

Null: There is no difference between project cost performance indicators that differentiate between poor project cost performance and good project cost performance during engineering/design, procurement and construction phases.

Alternative: There is a difference between project cost performance indicators that differentiate between poor project cost performance and good project cost performance during engineering/design, procurement and construction phases.

Hypothesis 2:

Null: There is no difference between project schedule performance indicators that differentiate between poor project schedule performance and good project schedule performance during engineering/design, procurement and construction phases.

Alternative: There is a difference between project schedule performance indicators that differentiate between poor project schedule performance and good project schedule performance during engineering/design, procurement and construction phases.

1.4 Research Contributions

The successful completion of this research helps scholars and practitioners in the field of construction management to improve their understanding of phase-based project success. This research contributes to the field of construction engineering and management in two major ways. First, it identifies project factors/characteristics which drive poor project cost and schedule performance during the engineering/design, procurement and construction phases. Secondly, it determines the robustness of each of these cost and schedule performance indicators during the engineering/design, procurement and construction phases, which assists project managers to allocate their resources more effectively. Identifying and understanding phase-based cost and schedule indicators could potentially benefit high level managers of contracting companies in the decision making process regarding how to proceed with a specific project execution strategy. Same could also help the owners to have a more realistic view of the time and cost associated to the process of project development.

1.5 Study Limitations

This study focuses on identifying factors which influence project cost and schedule performance during the engineering/design, procurement and construction phases. The limitations of this study are as follows:

(1) It is based on the Construction Industry Institute (CII) complexity project survey data;

(2) It is derived from a limited number of data points;

(3) It considers only cost and schedule as project success drivers;

(4) It is focused on heavy industrial construction projects.

1.6 Dissertation Outline

This document is presented in nine sections. Following this Chapter, which mainly focused on introduction and problem statement, objectives, research questions and limitations, Chapter 2, focuses on literature study of the relevant past research in construction cost estimation, construction cost performance and construction schedule performance. In Chapter 3, the description of the methodology and data set utilized in this study are discussed. The results of the preliminary data assessment are presented in Chapter 4. Next, Chapter 5 discusses how the missing data is handled and normalized, and also explains the statistical data analysis used to achieve the objectives of this study. Then, the outcome of the stepwise regression and construction knowledge implementation are presented in Chapter 6. Chapter 7 presents the results of the phase-based cost and schedule all-possible combination regression models. Chapter 8 discusses uncertainty analysis of each of the mentioned models using Extreme Bounds Analysis (EBA). Finally, conclusions and directions for future work are presented in Chapter 9.

2. LITERATURE REVIEW

2.1 Project Success

Although a number of researchers have explored the concept of project success, no general agreement was achieved. The true meaning of project success is constantly evolving and the criteria of project success are constantly revised. For the previous several decades, project management researchers have been constantly trying to find out and formulate key factors leading to project success (e.g. Baker et al., 1988, Pinto and Slevin, 1988, and Lechler, 1998). A number of studies have investigated the nature of the term ‘Project Success’. Some conceptualize it as a one-dimensional construct that is mainly shaped around meeting project budget, time, and quality (Brown and Adams, 2000, Bryde, 2008, Fortune et al., 2011, Müller and Turner, 2007, Turner, 2009 and Wateridge, 1995). Others have considered project success as a complex, multi-dimensional concept with more attributes (Atkinson, 1999, Jugdev and Muller, 2005, Lim and Mohamed, 1999, Lipovetsky et al., 1997 and Shenhar et al., 2001). Despite numerous attempts in the Project Management (PM) domain to define project success and to assess it meaningfully, studies have concluded that a sizeable portion of projects do not meet their objectives and some even fail altogether (Cicmil and Hodgson, 2006, Lee and Xia, 2005, Papke-Shields et al., 2010, Pich et al., 2002 and The Standish Group, 2009).

Therefore, within the construction domain, there is a continuing need for a systematic review of the existing literature in order to develop a framework for measuring project success in both quantitative and qualitative terms, and identify factors that positively or adversely influence project success.

2.2 Critical Success Factors

Almost all researchers agree that project success can be generally attributed to certain key project characteristics, also referred to as critical success factors (CSFs). Some researchers have focused on identifying CSFs (Belassi and Tukel, 1996, Cooke Davies, 2002, Fortune and White, 2006 and Pinto and Slevin, 1987), and provided a list of potential factors that assist with understanding the phenomenon of project success or failure. However, a major limitation still exists in that it is still very difficult to categorize and reduce CSFs to a manageable number (Stefanovic, 2007). Although some CSFs stand out in this long list of potential factors, there is only limited agreement among researchers of different fields on critical factors and their individual influence on project success (Fortune et al., 2011), and studies have not yet identified a compelling model of the CSFs. Based on an extensive review of the project success literature, Muller and Jugdev (2012) concluded that a clear definition of project success does not exist, and thus, there is a need to develop meaningful and measurable constructs of project success. In reporting this conclusion, they also indicated that the research theorizing CSFs is not sufficient in meeting this objective.

In search for reasons of project success and failure, Murphy et al. (1983) utilized stepwise regression analysis on data from 670 projects pertaining to construction, manufacturing, and research and development (R&D). Pinto and Slevin (1989) tried to set aside the convenient research trend of treating all project types as similar, and used stepwise regression analysis on 335 survey responses (55 percent for construction; 45 percent for R&D) for seeking separate sets of CSFs for construction and R&D projects. In their study, the phases of project lifecycle that were considered included conceptualization, planning, execution, and termination. It was stated that every project type offers its own distinct set of CSFs, and the set even varies over a project's lifecycle.

Chua et al. (1997) applied neural networks to data from 75 construction projects to determine CSFs for budget performance. Kog et al. (1999) used the same approach for determining CSFs for schedule performance of construction projects. Both Chua et al. (1997) and Kog et al. (1999) only used tangible factors, and hence, their data qualified for utilizing the neural networks technique.

Later, Kog and Loh (2012) studied a possible dissimilarity between CSFs pertaining to different components of construction projects, namely civil, architectural, mechanical and electrical, and quantity surveying. Due to the intangibility of the CSFs utilized in their research, they used analytical hierarchy process (AHP) for CSF extraction. With one component at a time, separate CSF lists were compiled for the objectives of project budget, schedule, quality, and overall performance. The study concluded that in general, distinct sets of factors were perceived as crucial by professionals associated with the four components.

Oisen (1971) suggested cost, time, and quality as the success criteria bundled into the description. Many other researchers, namely Turner (2009), Morris and Hough (1987), Wateridge (1998), De Witt (1998), McCoy (1987), Pinto and Slevin (1988), Saarinen (1990), and Ballantine (1996) also agree that cost, time, and quality should be used as key success criteria, but not exclusively. However, Wright (1997) looks at the problem from a point of view of a customer and reduces this list, suggesting that only two parameters are of importance, time and budget.

In the research presented in this dissertation, ‘Project Success’ is defined as the extent to which budget and schedule milestones are achieved as perceived by project participants in the capacity of owners, contractors, construction managers, and designers.

2.3 Construction Cost and Schedule Overrun

According to Abbas (2006), delay is the late completion of a construction project compared to the planned schedule or contract schedule. In short, delay occurs when the progress of a contract falls behind schedule. Delay may be caused by any party to the contract and may be a direct result of one or more circumstances. A delay in contract can have adverse effects on both the owner and the contractor (either in the form of lost revenues or extra expenses) and it often raises the contentious issue of responsibility for the delay, which may result in conflicts and litigation issues. A cost overrun occurs when the final cost of the project exceeds the original estimates (Leavitt et al., 1993; Azhar and Farouqi, 2008). A cost overrun is the increase in the amount of money required to construct a project over and above the original budgeted amount. Datta (2002) described cost escalation as a ubiquitous problem in government projects in India. There is a relationship between the schedule, the scope of work, and project conditions. Changes to any one or more of these can affect the budget and the time of completion. It has been argued that it is necessary to create awareness of the causes of project schedule delays, their frequency, and the extent to which they adversely affect project delivery (Al-Khalil and Al-Ghafly, 1999). Anderson et al. (2016) studied best scoping practices to improve on-time and on-budget delivery of highway projects. Kaliba et al. (2009) found that the major causes of delays in road construction projects in Zambia were delayed payments, financial deficiencies of the client or the contractor, contract modifications, economic problems, material procurement issues, changes in design drawings, staffing problems, equipment unavailability, improper or lack of supervision, construction mistakes, poor coordination on the site, changes in specifications, and labor disputes and strikes. El-Razek et al. (2008) found that delayed or slow delivery of payments, coordination problems, and poor communication were important causes of delay in construction projects in Egypt. Sambasivan and Soon (2007) found that poor planning, poor site management, inadequate supervisory skills on the part of the contractor, delayed payments, material shortages, labor supply shortages, equipment unavailability and/or failure, poor communication, and rework were the most important causes of delays in the Malaysian construction industry. Kouskili and Kartan (2004) identified the main factors affecting cost and time overrun as inadequate/inefficient equipment, tools and plants, unreliable sources of materials on the local market, and site accidents. Le-Hoai et al. (2008) identified the top three causes of cost overruns in Vietnam as material cost increases due to inflation, inaccurate quantity takeoffs, and labor cost increases due to environmental restrictions. In their research, Kaliba et al. (2009) concluded that cost escalation of construction projects in Zambia was caused by factors such as adverse weather, scope changes, environmental protection, mitigation costs, schedule delays, strikes, technical challenges, and inflation. Bubshait and Al-Juwait (2002) listed the following as factors that cause cost overruns on construction projects in Saudi Arabia: weather, the number of simultaneous projects, social and cultural impacts, project location, lack of productivity standards, competition level, supplier manipulation, economic instability, inadequate production of raw materials, and absence of construction cost data.

Kaming et al. (1997) used a questionnaire survey in Indonesian high-rise construction projects, and subsequently identified 11 variables of delays and seven variables of cost overruns. Out of these variables, they stated that increase in material cost due to inflation, inaccurate quantity take-off, and increase in labor cost due to environmental restriction are the first three causes of cost overruns. They also reported that design changes, poor labor productivity, inadequate planning, material shortage, and inaccuracy of material estimates are the first five causes of schedule delays. Utilizing a person-interview survey of 450 randomly selected private residential project owners and developers in Kuwait, Koushki et al. (2005) identified estimates of time delays and cost increases and their causes. According to their research, the three main causes of delays are change orders, owner's financial constraints, and owner's lack of experience. The same study concluded that the first three causes of cost overrun are contractor-related problems, material-related problems, and owner's financial constraints. They recommended that in order to minimize time delays and cost overruns, project owners should require the availability of adequate funds, allocation of sufficient time and money at the design phase, and selection of a competent consultants and reliable contractor to carry out the work. Frimpong et al. (2003) carried out a questionnaire survey in Ghana groundwater construction projects. They listed and ranked 26 factors responsible for project delays and cost overruns. The Kendall's coefficient of concordance was used to test the degree of agreement between owners, contractors, and consultants, and the study concluded that there was insignificant degree of disagreement. Chang (2002) identified through four case project documents the reasons for cost and schedule increase, and further quantified their contributions to this problem for engineering design projects. These reasons were grouped into three categories of mainly within the owner's control, mainly within the consultant's control, and beyond either the owner's or consultant's control.

Similarly, many other researchers have been attracted to project delay problems, with several of them aiming at Asian and African countries. To name a few, in Southeast Asia, for example, these researchers are Ogunlana et al. (1996) in Thailand, Kaming et al. (1997) in Indonesia, Sambasivan and Soon (2007) in Malaysia, Chan et al. (1996), Kumaraswamy and Chan (1998), Lo et al. (2006) in Hong Kong, and Acharya et al. (2006) in South Korea. In Vietnam, large construction projects were studied by Long et al. (2004a) to identify project success factors, and by Long et al. (2004b) to identify common and general problems. Along the same lines, the government of Vietnam has also acknowledged construction delays and cost overruns as a major problem, especially in public projects (Ministry of Planning and Investment, 2003). In the Middle Eastern countries, the construction boom resulting from the oil and natural gas exports has consumed many research efforts in the area of project cost and schedule overruns. Examples of past research include Assaf and Al-Hejji (2006) in Saudi Arabia, Koushki et al. (2005) in Kuwait, Faridi and ElSayegh (2006) in UAE, and Odeh and Battaineh (2002) and Sweis et al. (2007) in Jordan. In the U.S., Chang (2002) surveyed the construction industry, while in Africa, Frimpong et al. (2003) studied the industry in Ghana, and Mansfield et al. (1994) and Aibinu and Odeyinka (2006) carried out their work in Nigeria.

2.4 Summary

In this Chapter, the concept of “project success” and researchers’ point of view regarding the CSFs have been studied and investigated. Although project success has been defined in several ways, this study was performed based on the Wright’s (1997) definition of the project success in terms of time and budget parameters. This Chapter also reviewed the existing literature on project cost and schedule overrun indicators and factors in different countries including Egypt, Zambia, Malaysia, Ghana, and Thailand. Moreover, this Chapter covered the research efforts that addressed project cost and schedule overruns in oil and gas projects in the Middle East. In next Chapter, the methodology to conduct this study and the utilized dataset are described in detail.

3. DESCRIPTION OF METHODOLOGY AND DATA SET

3.1 Methodology

Figure 1 illustrates the methodology utilized to conduct this study. This research framework highlights six major sections as shown:

(1) First, based on the existing literature, the problem of insufficient knowledge on project success indicators in each of the design/engineering, procurement and construction phases was identified. As explained earlier, project cost and schedule performances are considered as two major project success criteria.

(2) In the next step, the survey data which was collected to study project complexity and its impact (CII, 2016) were utilized to identify phase-based project cost and schedule performance indicators. It should be mentioned that since the collected survey data for the complexity project was very comprehensive, it was possible to perform further analysis to identify project cost and schedule performance indicators. Moreover, preliminary data assessment regarding the impact of company revenue, project nature, execution driver, and delivery method on cost and schedule performance has been performed.

(3) In this step, the issue of 17 percent missing data was addressed. For this purpose, since the data set was collected to measure project complexity and its impact, the project complexity level question was considered as the benchmark. More details on this are provided in Chapter 5.

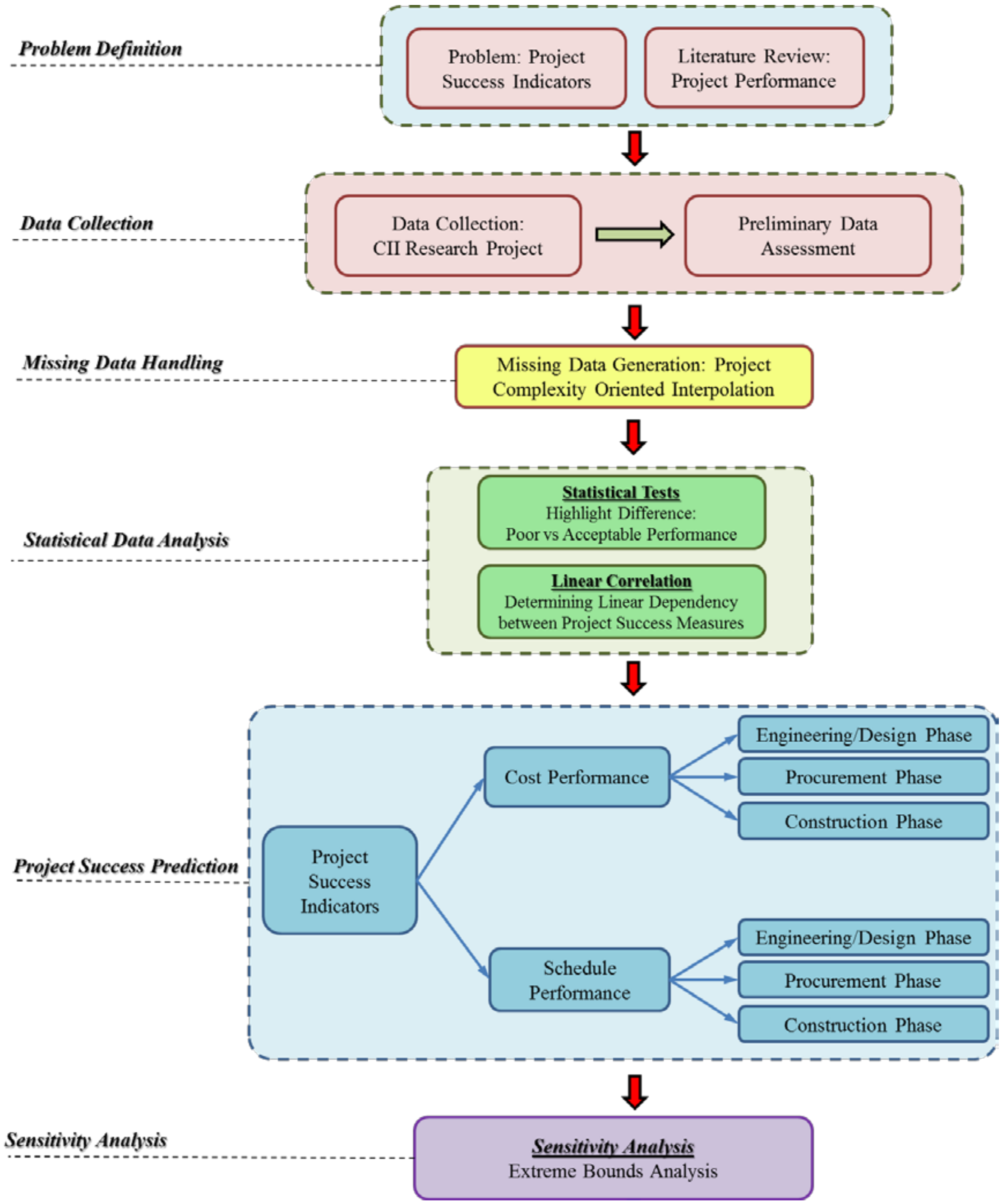

Figure 1. Research framework

(4) Subsequently, several statistical data analysis methods were used to narrow down the number of variables which could potentially impact project cost and schedule performance during design/engineering, procurement and construction phases.

(5) Next, all-possible combination regression method was used to finalize project success indicators during the engineering/design, procurement and construction phases. It should be noted that a project is assumed to be successful if it meets the estimated cost and schedule targets.

(6) Ultimately, sensitivity of the phase-based project cost and schedule performance indicators was analyzed. This sensitivity analysis which was performed using the Extreme Bounds Analysis (EBA) method, identifies which of the mentioned indicators are robustly associated with the project performance outcome. These results enable project managers to allocate their limited resources more effectively to accomplish their projects successfully.

3.2 Data Set

This study used the survey data which was collected for “measuring project complexity and its impact” research project awarded by the CII. Although this survey was developed to identify project complexity indicators, 150 other project parameters were also inquired and measured. Therefore, the collected data was comprehensive enough to study and identify project cost and schedule performance indicators during the engineering/design, procurement and construction phases. The survey structure and its details are shown in Appendix A.

Figure 2 illustrates the structure and components of the survey used to complete this study. As shown in this figure, this survey consists of the following three main categories:

- Project General Characteristics: this section of the survey collected information about the contractor's/client's company revenue, industry type of the project, project primary nature, project baseline schedule and cost estimate, owner/engineer/contractor-driven change orders during the design and construction phases, project execution driver, contract provisions and penalties for late delivery, project delivery method and type of the engineering and construction contracts.
- Project Specific Characteristics: in this section of the survey, information about the specific characteristics of the projects were requested, measured and collected. These specific characteristics which were classified into 11 categories include stakeholder management, governance, legal, fiscal planning, interfaces, scope definition, location, design and technology, project resources, quality and execution targets.
- Construction Best Practices: in this section of the survey, the implementation level of the CII best practices was inquired. At the time of this survey data collection, the following 11 strategies were considered as the CII best practices: constructability, team building, alignment process, partnering, front end planning, change management, materials management, zero accident techniques, planning

for startup, dispute review, quality management, lessons learned and risk assessment process.

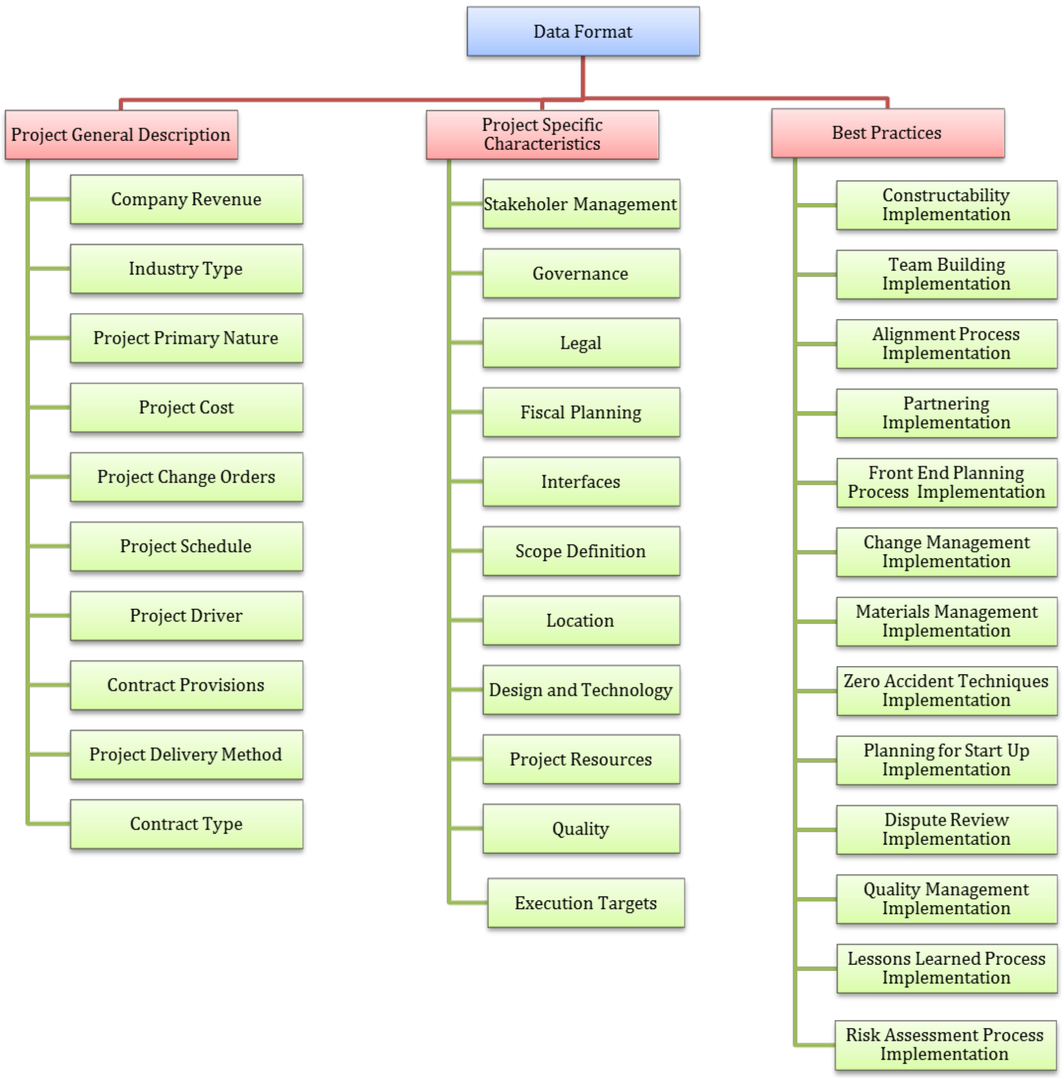

Figure 2. Survey data categories and variables

Upon the survey development, the research team performed nine pilot tests to receive constructive feedback and revise accordingly. When the survey was finalized and distributed, it was sent out to 140 construction professionals. After several followups, the research team was able to collect 44 projects (data points) from heavy industrial companies. Information on the job title and experience level of the survey respondents are shown in Table 1.

Table 1. Profiles of survey respondents

Demographic Respondent	Number of Responses
Job Title	
Project Manager	23
Project Staff	7
Construction Manager	5
Program Director	4
Portfolio Manager	3
Consultant	2
Years of Experience	
< 5	1
5 - 10	2
10 - 15	8
15 - 20	4
20 - 25	4
25 - 30	9
30 >	15

3.3 Summary

In this Chapter the overall methodology of identifying phase-based cost and schedule performance indicators was explained. In particular, the methodology of this study has six major steps: (1) problem definition, (2) data collection, (3) missing data handling, (4) statistical data analysis, (5) project success prediction, and (6) sensitivity analysis. Moreover, the format of the CII data set used to perform this study was described in detail. As described in this Chapter, a survey was used to measure the following three major project variables: project general characteristics, project specific characteristics and construction best practices. The job title as well as the survey respondents' number of years of experience have been reported in this Chapter as well. In next Chapter, the preliminary assessment of the data is performed and presented by analyzing the effect of project delivery method, project nature and project execution driver, and also the company's revenue on cost and schedule performance.

4. PRELIMINARY DATA ASSESSMENT

In this Chapter, the goal is to perform preliminary assessment of the data in order to analyze the effect of project delivery method, project nature and project execution driver, and also the company's revenue on cost and schedule performance. In doing so, good and poor project cost and schedule performances were also defined. In addition, the impact of change orders on cost and schedule performances is studied and explained.

Figure 3 depicts the revenue profile of companies that provided survey data. As shown in this figure, company revenues were divided into the following three levels:

- Small size (Revenue: 0 to $100 Million)
- Medium size (Revenue: $100 Million to $1.0 Billion)
- Large size (Revenue: Greater than $1.0 Billion)

This analysis revealed that most survey responses were provided by large size companies, followed by medium size firms. It is worth noting that such results were expected since most oil and gas industry firms have revenues of $100 million or more annually.

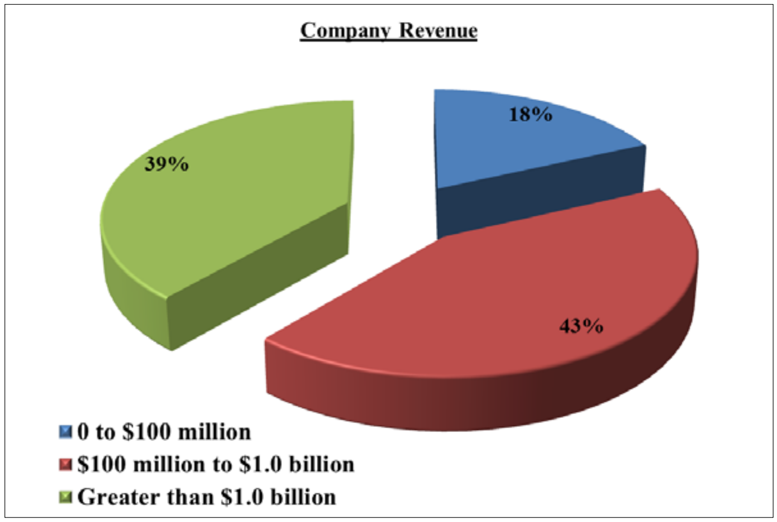

Figure 3. Company revenue profile from collected data

Figure 4 presents the nature of project data which have been utilized to conduct this study. Results show that most of the data points were related to modernization, renovation and/or upgrading existing facilities. It should be mentioned the least percentage of the responses were collected from brownfield type of projects.

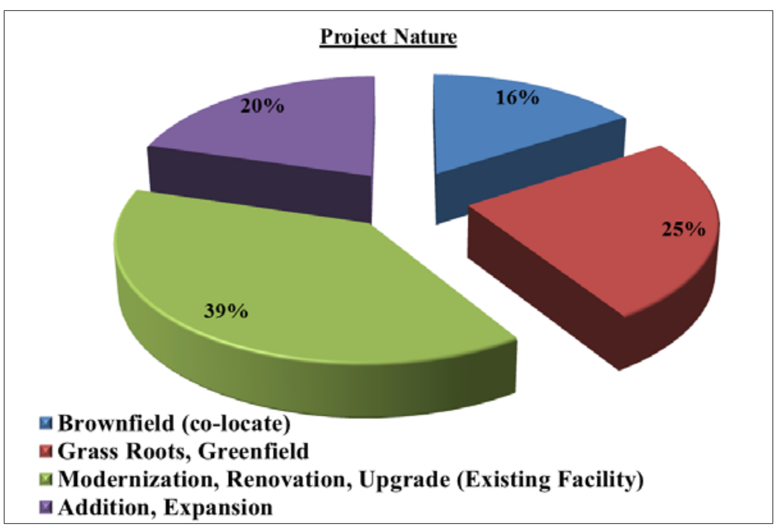

Figure 4. Project nature from collected data

Figure 5 demonstrates the distribution of data set project execution drivers. As shown in this figure, close to 60 percent of oil and gas industry projects are influenced by their schedule plan, and only less than 20 percent of these heavy industrial projects are influenced by cost as the main project execution driver. The main reason behind these numbers could be that profitability in almost all oil and gas projects is heavily tied to meeting schedule milestones.

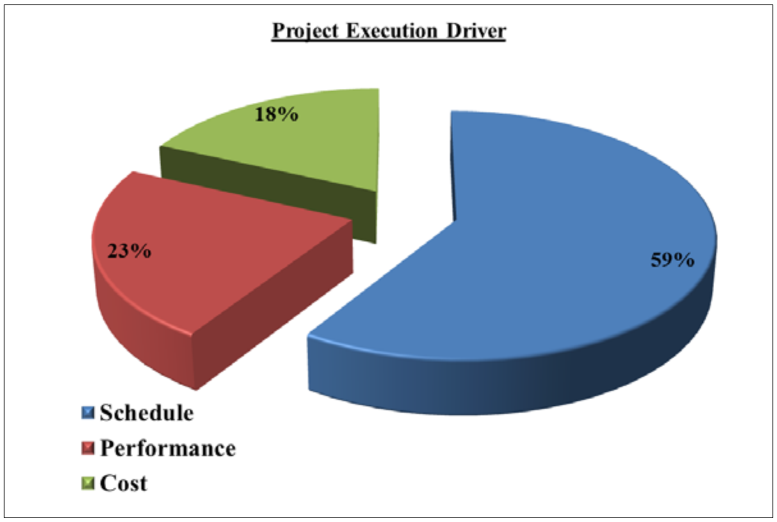

Figure 5. Project execution driver from collected data

Figure 6 illustrates that more than half of the projects in the oil and gas industry perform their construction activities under the design-build delivery method. The same analysis also reveals that although non-traditional project delivery methods are used to construct most of the facilities in this industry, about a quarter of projects are still executed under the traditional design-bid-build project delivery method.

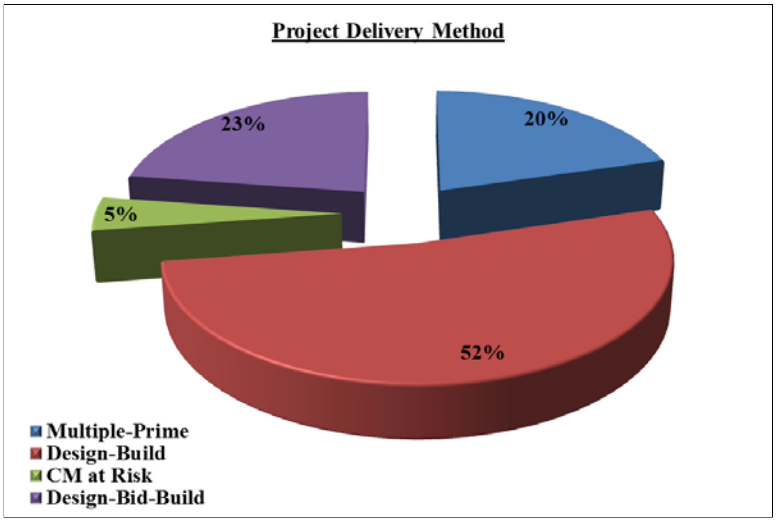

Figure 6. Project delivery method from collected data

4.1 Cost and Schedule Performance Definition

Most companies and literature suggest that owners usually face 5 to 10 percent delay and cost overruns. Therefore, firms need to allocate appropriate resources to address potential cost overrun and delay problems. Accordingly, this study considers a project within ±10 percent overrun in either or both schedule and cost to have an acceptable performance. Figure 7 shows how project cost and schedule overrun percentages determine the performance quality level.

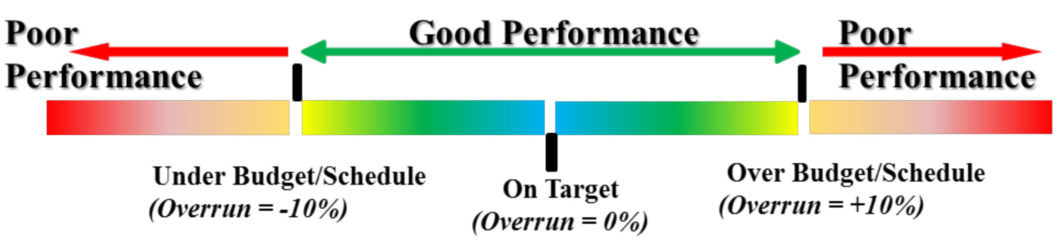

Figure 7. Cost and schedule performance definition based on overrun

4.2 Cost Performance Evaluation

Figure 8 compares company revenue levels from collected data for good cost performance projects versus the poor ones. The differentiation between projects with good and poor cost performance is based on Figure 7. It should be noted that the outside rings in Figure 8 through Figure 11 correspond to well performed projects in terms of cost, whereas the inside rings show statistics for projects with poor cost performance. The outcomes illustrated in Figure 8 indicate that the majority of poorly performed projects in terms of cost are reported by medium size companies. However, according to this figure, the majority of projects with good cost performance are reported by large size companies.

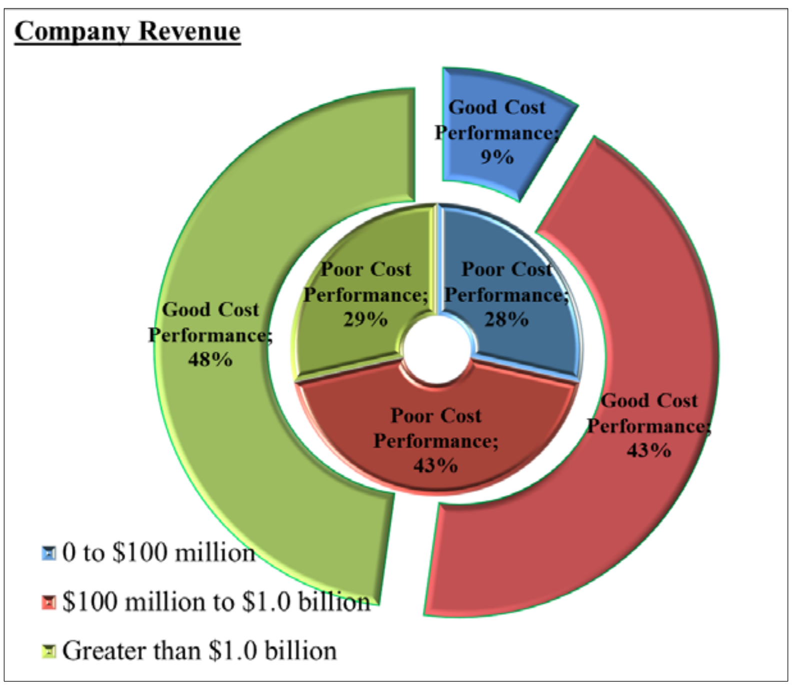

Figure 8. Company revenue from collected data for good vs. poor cost performance

Figure 9 assesses the project nature of good cost performance projects versus the poor ones. This figure indicates that while heavy industrial firms perform worse in modernization, renovation and/or upgrading project types, they have the capacity to construct grassroots/greenfield projects more successfully than brownfield and addition/expansion projects.

Figure 10 evaluates the project execution driver for good performance projects versus the poor ones. The results indicate that if schedule selected as a project execution driver, it could make a slight deviation in cost performance.

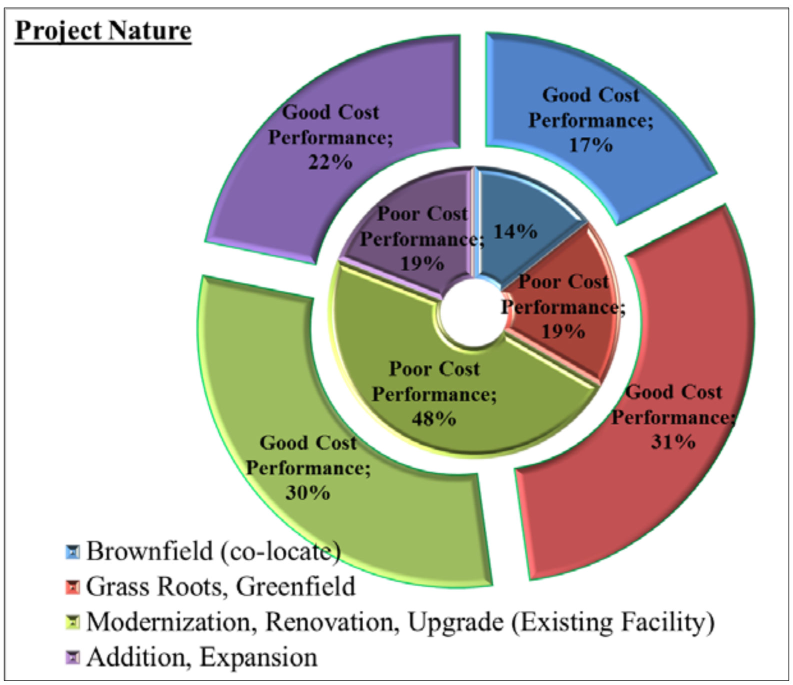

Figure 9. Project nature from collected data for good vs. poor cost performance

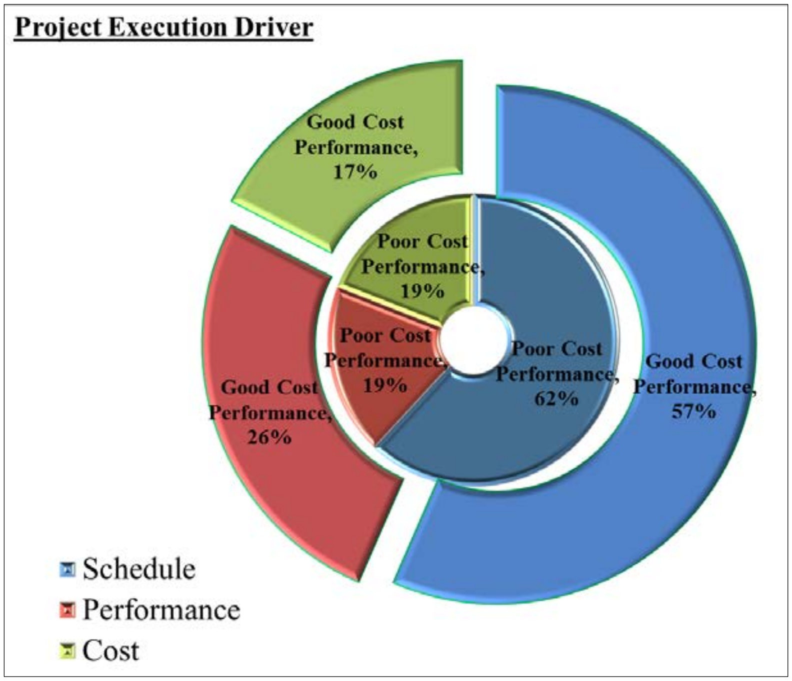

Figure 10. Project execution driver from collected data for good vs. poor cost performance

Figure 11 highlights how the selection of project delivery method could impact project cost performance. This graph indicates that the number of on-budget completed projects with design-build delivery is dominant compared to other methods. This figure also shows that the CM-at-risk is the least utilized project delivery method in the oil and gas industry.

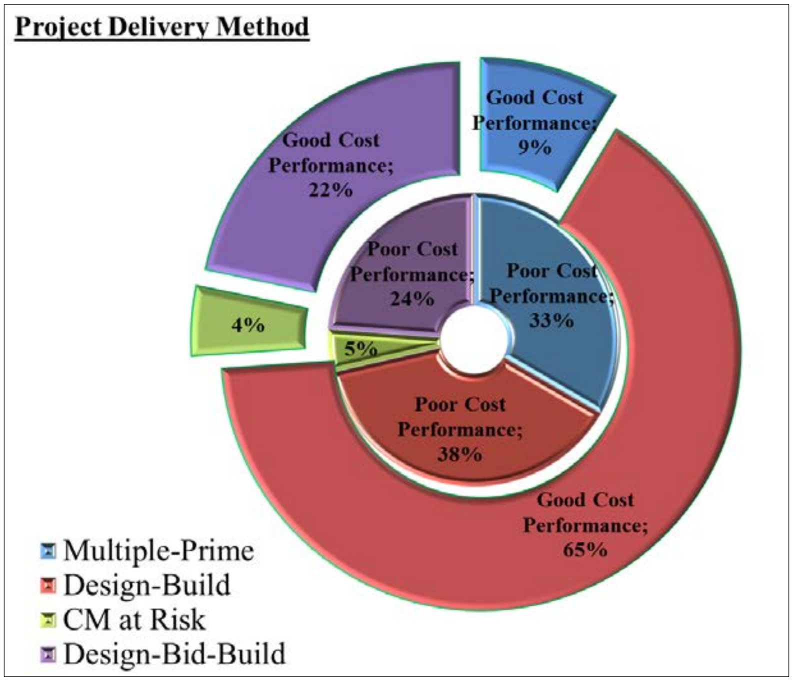

Figure 11. Project delivery method from collected data for good vs. poor cost performance

4.3 Schedule Performance Evaluation

Figure 12 expresses that large and medium size companies (i.e. revenues greater than $100 million) could complete more projects on schedule compared to small size firms (i.e. revenues less than $100 million). It also shows that between these two groups, large size companies are more likely to finish their projects with less schedule deviation. The differentiation between projects with good and poor schedule performance is based on Figure 7. It should be noted that the outside rings in Figure 12 through Figure 15 correspond to well performed projects in terms of schedule, whereas the inside rings show statistics for projects with poor schedule performance.

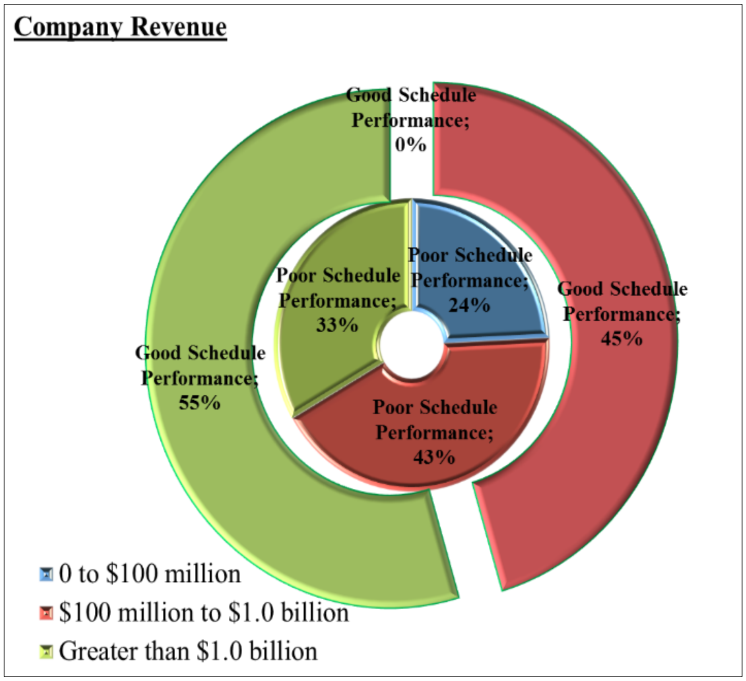

Figure 12. Company revenue from collected data for good vs. poor schedule performance

Figure 13 compares the nature of projects completed on schedule with the ones which are behind the schedule. It shows that project nature does not cause a great difference in schedule performance.

Figure 14 evaluates the impact of delivery method on project schedule performance. Similar to the relationship between project delivery and cost performance, the design-build delivery method has a greater chance to result in an on-time and successful project completion in the oil and gas industry. Also, from this figure, it can be concluded that the multiple-prime delivery method results in a higher percentage of projects with poor schedule performance than on-time projects.

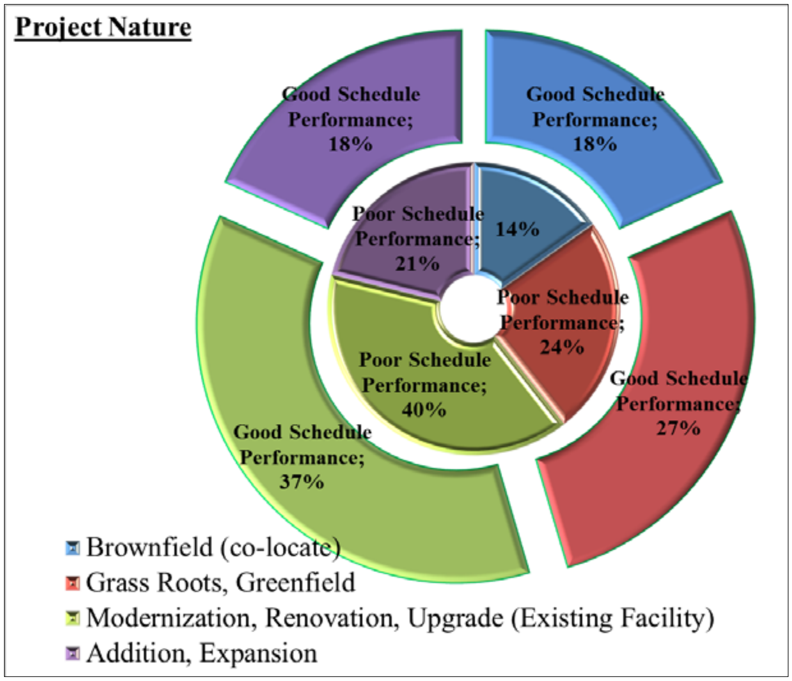

Figure 13. Project nature from collected data for good vs. poor schedule performance

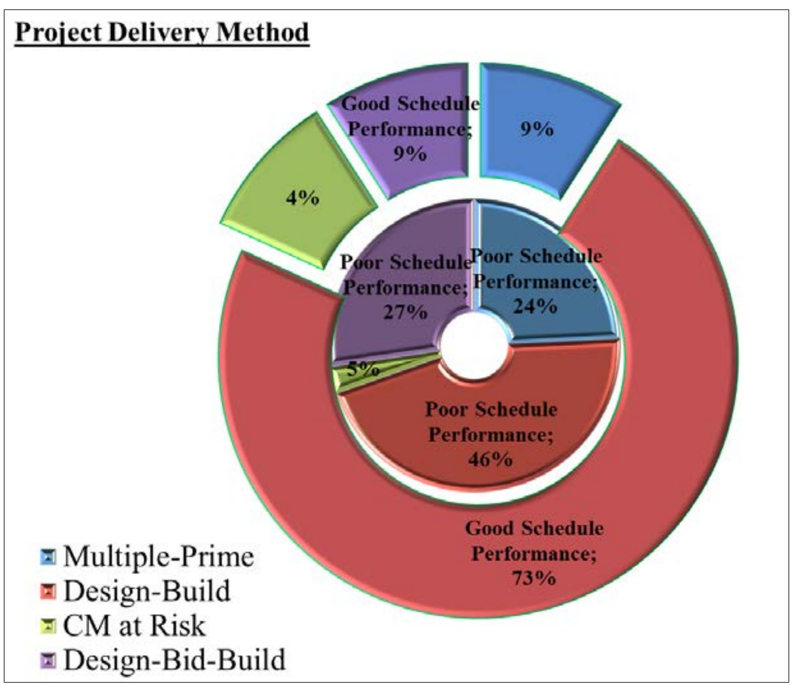

Figure 14. Project delivery method from collected data for good vs. poor schedule performance

Figure 15 assesses how project execution driver impacts project schedule performance. This figure reveals the two following conclusions:

- In general, most projects in the oil and gas industry select schedule as the primary project execution driver.
- If schedule is selected as the project execution driver, the project has a greater chance to be completed on-time. This result is similar to the findings of the impact of execution driver on cost performance.

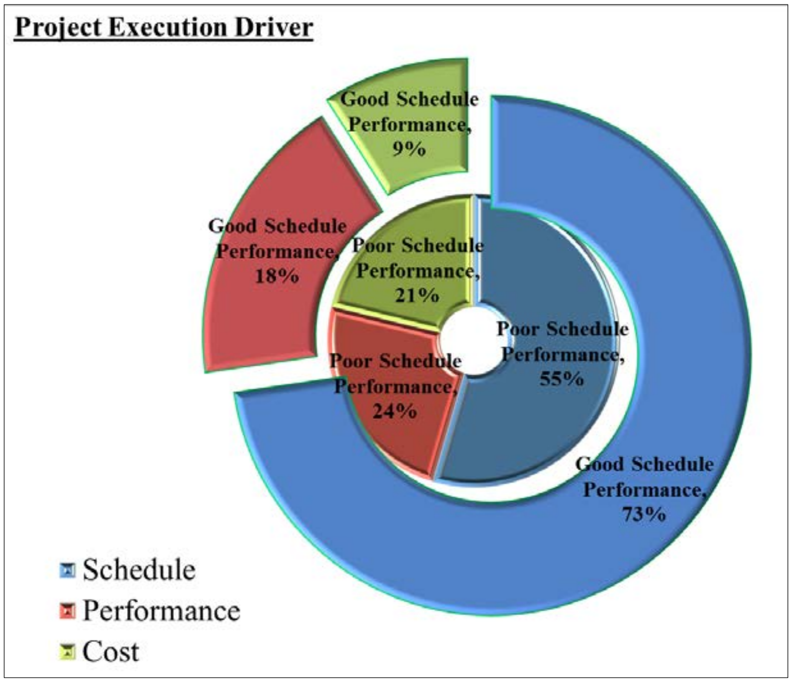

Figure 15. Project execution driver from collected data for good vs. poor schedule performance

4.4 Impact of Change Orders on Project Cost and Schedule

Multiple change orders are approved during the project or remain unresolved until the end of the project, leading to large delay and cumulative impact on project cost. Figure 16 and Figure 17 illustrate the project cost overrun data versus change orders and the project delay data versus change orders, respectively. It is seen that project change orders have a direct relationship with project cost and schedule overrun. Additionally, the plotted data reveal that overruns are not solely due to the issuance of change orders, as even some projects that did not have any change orders still experienced some levels of cost and schedule overruns.

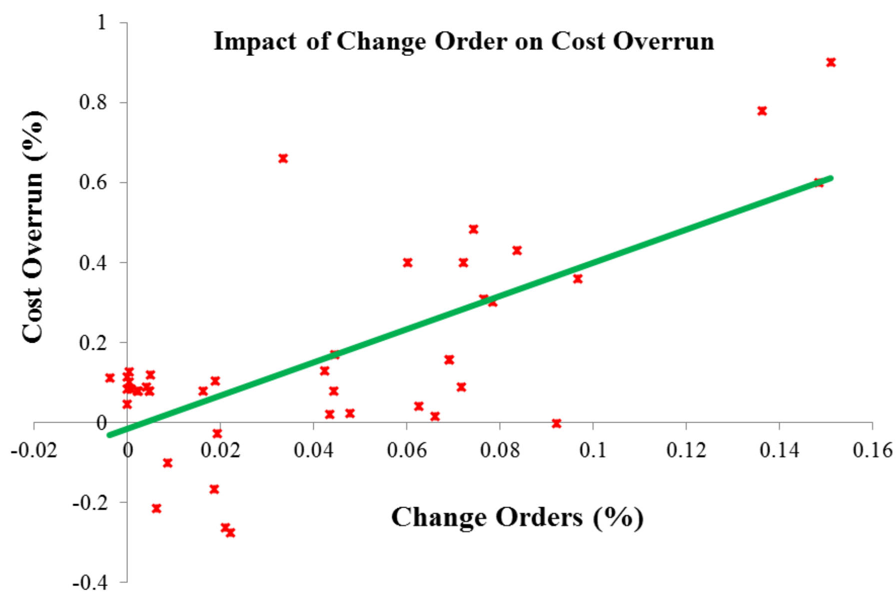

Figure 16. Impact of change orders on cost overrun (n = 44, R^2 = 0.49)

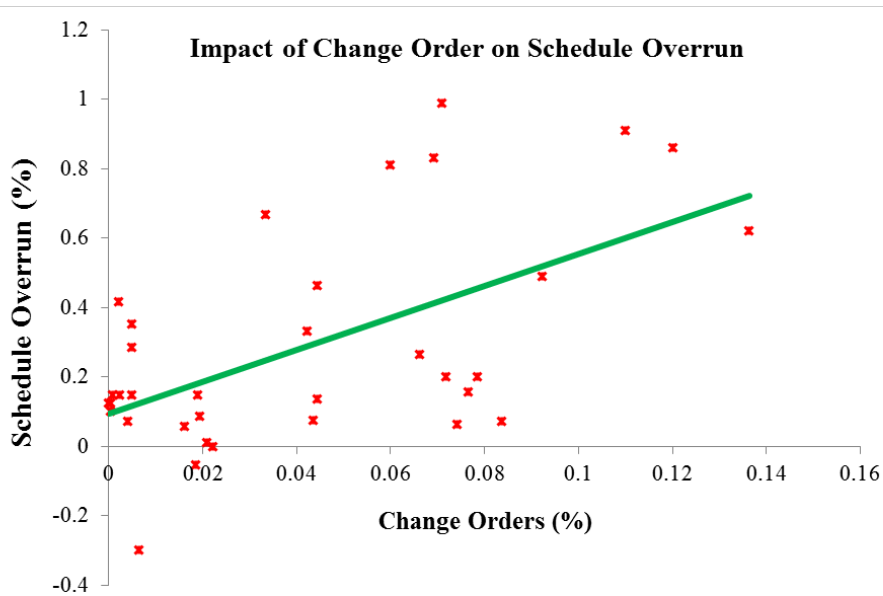

Figure 17. Impact of change orders on schedule overrun (n = 44, R^2 = 0.34)

4.5 Summary

In this Chapter, the preliminary assessment of the data was performed and presented. In particular, the effect of project delivery method, project nature and project execution driver, and also the company's revenue on cost and schedule performance was analyzed. Also, good and poor project cost and schedule performances were defined. Finally, the impact of change orders on cost and schedule performances was studied and explained. In next Chapter, the framework and details of the statistical methods used to analyze the data are discussed, and the process of handling missing data points using the mean value substitution is explained.

5. STATISTICAL DATA ANALYSIS

In this Chapter, the process of handling missing data and statistical data analysis used in this research are presented and explained in detail. As shown in Figure 18, the first step to conduct this part of the research is handling missing data. Since data values have been measured on different scales (e.g. budget scale is measured in dollars and schedule in months), z-score transformation methodology is applied to make a standard normalized scale for all the data points. To explain more, all survey responses have been transformed to z-score values to have all the data on the same scale.

Then, in order to determine significant construction cost and schedule performance indicators in engineering/design, procurement and construction phases, the following two statistical analysis methods including correlation analysis and statistical significance tests were performed:

- **Linear correlation:** Pearson/Spearman correlation analysis between construction independent variables (project characteristics and best practices) and construction cost and schedule overrun during engineering/design, procurement and construction phases was performed. In this analysis, those independent variables were selected which were both statistically significant (their p-value was less than 0.05) and had a correlation value of more than 0.25. The reason for setting the correlation value as low as 0.25 was to ensure a greater number of variables would be included in the next screening phase.

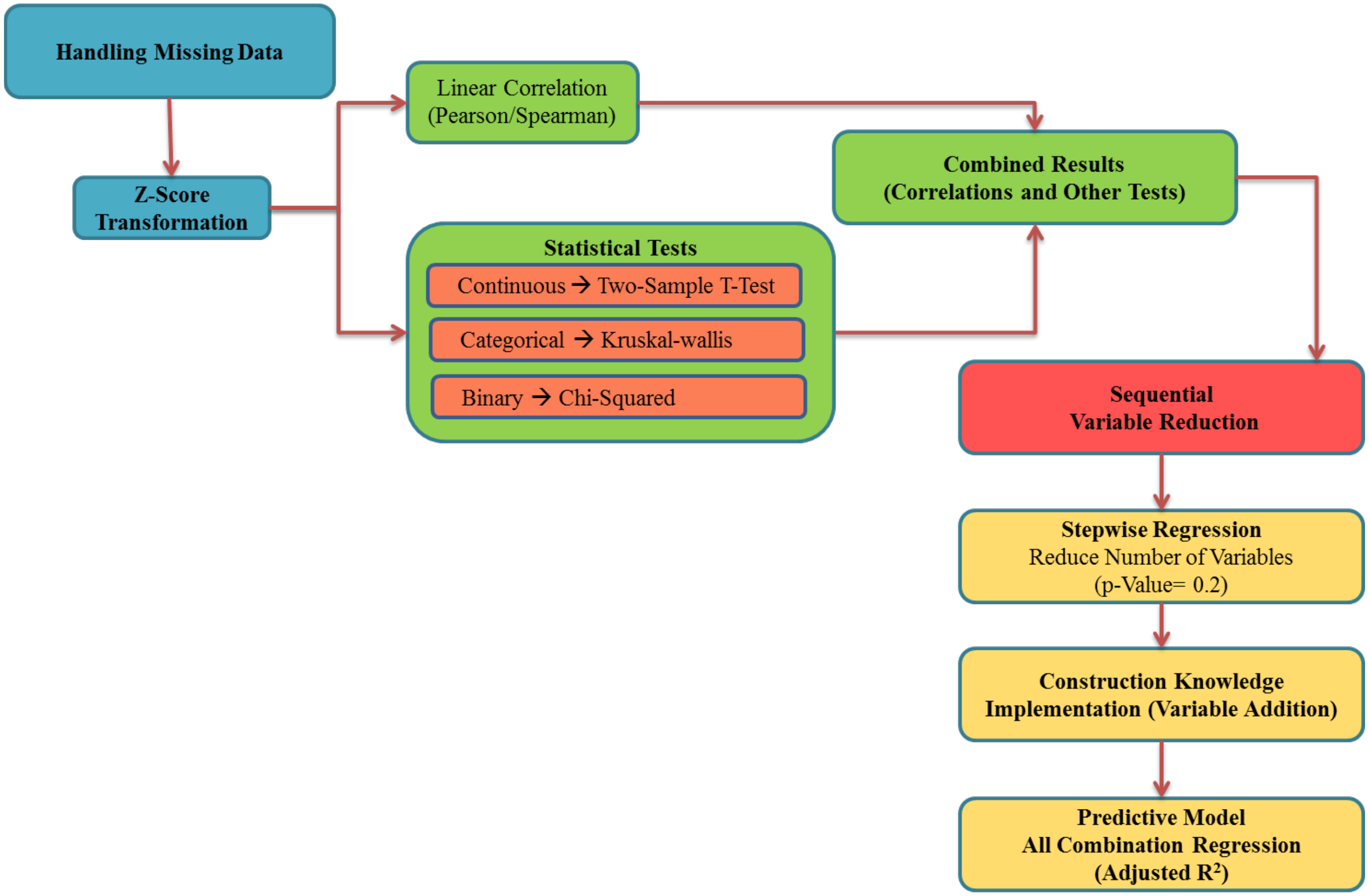

Figure 18. Data analysis framework

- **Statistical tests**: depending on the type of data, three significance tests were utilized to determine project cost and schedule performance indicators in engineering/design, procurement and construction phases. The statistical test algorithm was chosen based on the variable measurement types including continuous, categorical and binary variables. The tree statistical tests are as follows:
    - Two-Sample T-Test: This test is used when it is safe to assume that the data follows a normal distribution. T-Test is used in cases where the response is a count or other numerical values.
    - Kruskal-Wallis Test: This test is used for likert-scale data, where it cannot necessarily be assumed that the data follows a normal distribution.
    - Chi-Squared Test: This test is used for data points with a yes/no (binary) response, testing whether the observed frequencies of yes and no is what would be expected if good and poor project performance groups were in fact not different.

The outcomes of correlations and statistical tests with acceptable significance (p-values less than 0.1) are extracted and then combined to form the input for sequential variable reduction step. It should be noted that the reason to increase p-value from 0.05 to 0.1 was to ensure that a greater number of variables would be included in the next screening phase.

In the next step of the methodology, sequential variable reduction, independent variables/factors are carefully evaluated and reduced to exclude those variables which could not be used to predict the phase-based cost and schedule performances due to the timing of the occurrence. For instance, if the value of *"contractor driven change orders"* became a significant variable for predicting *"engineering phase cost overrun"*, the model could not utilize such variable as it is unknown by the time of predicting engineering phase cost overrun.

The ultimate objective of this part of the methodology is to identify leading indicators of cost overrun and schedule delay. Since the number of variables used as *"predictors"* are relatively high after sequential variable reduction step, understanding these variables might be less useful and informative for project managers to allocate their limited resources efficiently and effectively. The goal is to identify where project managers should allocate more human and equipment resources to improve project cost and schedule performance during the design/engineering, procurement and construction phases. Consequently, further variable reduction on the number of "predictor variables" was necessary. Therefore, to further narrow down the number of project cost and schedule performance determinants and identify the phase-based leading performance indicators, stepwise regression was utilized. The p-value margin of the stepwise regression to screen the performance indicators was raised to 0.20 to account for more variables mainly due to having low number of data points.

Since experience and practice play significant role in identifying project performance indicators, "construction knowledge implementation" step was added. In this part of the study, construction knowledge contributed to statistics in finalizing phase-based cost and schedule performance identification. In this part, those variables/indicators which were not statistically significant in earlier screening phases, were studied and evaluated. The goal was to include those excluded performance variables/indicators which based on construction experience were believed to have potential phase-based performance predictability. This construction knowledge addition step was added since the number of the collected data points were limited and also, the last step of the screening phase would exclude them if they were not again statistically significant. Therefore, variables which could not pass earlier mathematical filtration, but yet have potential to be considered as performance indicators, will be included in the all-possible combination regression screening phase.

Once significant project independent variables are extracted and finalized from mentioned procedures, the final set of phase-based cost and schedule overrun leading indicators are identified using all-possible combination regression method. This step selects and finalizes variables/characteristics based on their highest adjusted R-squared and/or lowest root mean squared error (RMSE). In order to improve project cost and schedule overruns, these leading indicators should be primarily focused on at the beginning of each phase. Figure 19 shows the simplified variable reduction process to determine phase-based cost and schedule performance indicators. The details of this step along with the final results are presented in Chapter 7.

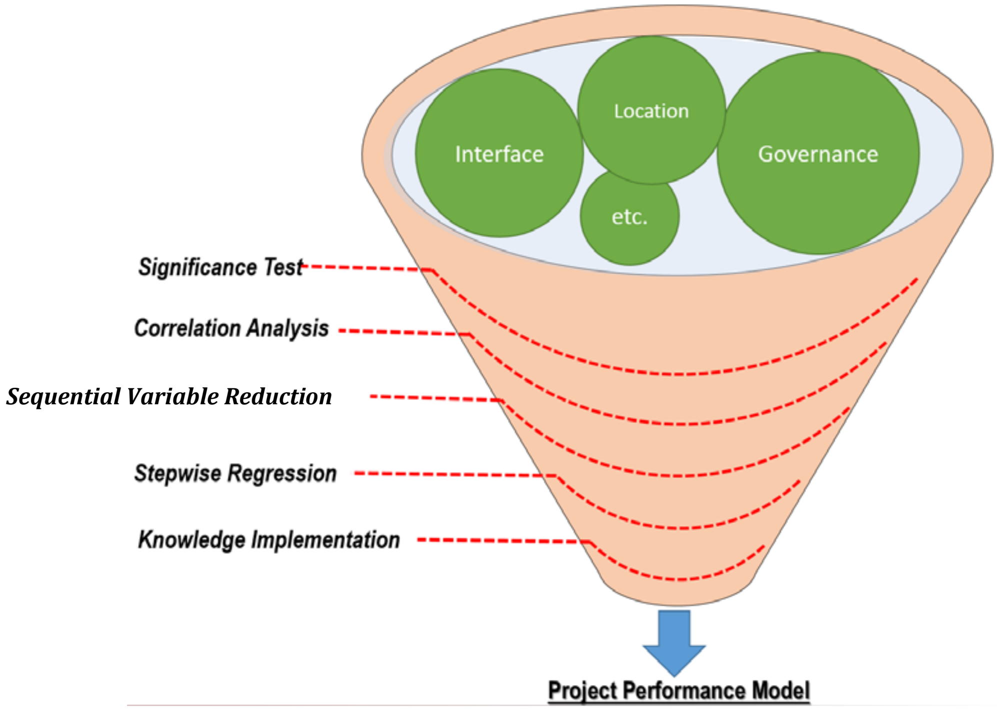

Figure 19. Screening process to develop phase-based cost and schedule performance indicators

5.1 Handling Missing Data

Since the number of the collected data points in this study is fairly limited, ignoring missing values will leave even fewer number of responses for the analysis. Therefore, retaining the data points and properly compensating for missing data is inevitable. Due to the fact that 17 percent of the data for this research is missing, having a proper methodology to estimate the missing values was fairly critical.

The missing data should be handled differently depending on why and where this occurred. The reason for having missing data in this study was mainly due to the nonresponse questions on the survey which has some interdependency to other given data in the same survey. Therefore, missing data is not generated at random and cannot be handled by simply generating random numbers.

To handle missing data in this study, mean value substitution method was utilized. Mean value substitution method replaces each missing value for a variable with the average of the observed values (Little and Rubin, 2014). Since this survey was primarily developed to measure project complexity, response to the "project complexity level" question was used as a benchmark to handle missing data. In the survey, respondents were asked to determine their project complexity level on a scale of 1 to 7. To handle missing data, projects with the same complexity level were clustered together. Then, each missing point was substituted by the mean value of the responses for the same variable in the same complexity level cluster. For instance, if one of the respondents did not provide information about the "value of the change orders during the construction phase" for a project with complexity level of 6, this missing data was substituted with the mean value of the "value of the change orders during the construction phase" for all projects with the complexity level of 6. In this manner, all missing data points were properly generated and handled.

5.2 Data Z-Transformation

The collected data were divided into three main variable types of continuous, categorical and binary. These data which have different metrics, could not deliver appropriate results unless transformed to be on the same scale. Therefore, *z*-transformation was used which is also called standardization or auto-scaling.

The application of the data standardization or data normalization, also known as *z*-score transformation, provides a way of normalizing data across a wide range of collected data and allows comparison of different values regardless of their original intensities. The process of transforming *X* values into z-scores serves two useful purposes:

- Each *z*-score determines the exact location of the original *X* value within the distribution.
- The *z*-scores form a standardized distribution can be directly compared to those of other distributions that also have been transformed into *z*-scores.

The *z*-score accomplishes this goal by transforming each *X* value into a positive or negative number. The sign is an indicator of whether the score is located above (+) or below (-) the mean, and the number tells the distance between the score and the mean in terms of the number of standard deviations.

5.3 Correlation Analysis

The purpose of the correlation analysis was to discover whether there was a relationship between variables, and find out the direction of the relationship. The outcome of the correlation analysis determines whether this relationship is in a positive or negative direction and also what is the strength of this relationship between the two variables. In statistics, the Pearson correlation is a measure of the linear correlation (dependence) between two variables *X* and *Y*, giving a value between +1 and −1 inclusive, where +1 indicates total positive correlation (agreement), 0 is no correlation, and −1 shows total negative correlation (disagreement). In this section, the correlations between potential performance indicators with phase-based cost and schedule overrun are measured. The goal is to investigate the strength (correlation coefficient values) and directions (sign of correlation coefficient) of the relationship between project independent variables and phase-based cost and schedule overrun.

First, the strength and significance (p-value) of the correlation between potential performance indicators and total cost overrun is calculated. Table 2 shows the independent project variables which are statistically significant (p-value less than 0.1) and have a correlation value of more than 0.25. In this table, the correlation significance level of less than 0.01 is denoted with **, and between 0.01 and 0.05 is shown with *. As shown in Table 2, depending on the value of the correlation, the cells are color coded from red to light blue. If the value of the correlation is higher than 0.70 or less than -0.70, it is colored in red. If the correlation value is between 0.50 and 0.70 or between -0.50 and -0.70, it is colored in orange. In the same table, if the correlation value is between 0.30 and 0.50 or between -0.30 and -0.50, it is colored in green. Any correlation value between 0.25 and 0.30 and also between -0.25 and -0.30 is colored in light blue. The reason for lowering the correlation value cut-off point to ±0.25 and increasing the p-value cut-off for the significance level is to include a greater number of the independent variables to the next screening phase (Sequential variable Reduction).

Table 2. Correlations between project characteristics independent variables and project total cost overrun

Project Total Cost Overrun	Correlation	P-value
Project Total Schedule Performance	-0.35	0.021*
Project Schedule Overrun	0.27	0.075
Project Total Cost Performance	-0.66	0.000**
Total Change Orders	0.32	0.037*
Total Owner Driven Change Orders	0.32	0.037*
Percentage of PM Staff Turnover	0.31	0.038*
Project primary Nature	-0.46	0.002**
Field Craft Labor Quality Issues	0.31	0.040*
Frequency of Workarounds - Unavailability of Materials	0.32	0.033*
Delay in Delivery of Permanent Facility Equipment	0.42	0.004**
Difficulty in System Design and Integration	0.42	0.005**
Impact of Project Location on Project Execution Plan	0.29	0.055
Project Population Density	-0.29	0.053
Impact of Request for Information (RFI) on Project Design	0.34	0.025*
Design Percentage Completion Prior to Project Budget Authorization	-0.47	0.001**
Clarity of Projects Scope During Designer/Contractor Selection	0.27	0.074
Communication Effectiveness within Designers/Engineers Group	0.30	0.049*
Number of Permitting Agency Organizations	-0.27	0.076
Number of Subcontractor Organizations	0.39	0.009**
Number of Joint Venture Partners (Contractors)	0.26	0.092
Number of Financial Approval Authority Thresholds	0.27	0.077
Alignment Quality of Internal Stakeholders	0.28	0.063
Number of Active Internal Stakeholders in Decision Making Process	0.30	0.045*
Engineering/Design Phase Baseline Schedule	-0.25	0.099
Value of Owner Driven Change Orders-Engineering/Design Phase	0.35	0.020*
Project Procurement Schedule Performance	-0.48	0.001**
Procurement Phase Schedule Overrun	0.40	0.008**
Procurement Phase Cost Overrun	0.48	0.001**
Project Cost and Schedule Performance	-0.65	0.000**
Project Engineering Schedule Performance	-0.31	0.040*
Engineering/Design Phase Schedule Overrun	0.31	0.041*
Project Engineering Cost Performance	-0.44	0.003**
Engineering/Design Phase Cost Overrun	0.53	0.000**
Project Construction Schedule Performance	-0.29	0.054
Project Construction Cost Performance	-0.57	0.000**
Construction Phase Cost Overrun	0.73	0.000**
Total Engineering Phase Change Orders	0.37	0.014*

Table 3 shows the strength and significance of the correlation between project characteristics and engineering/design phase cost overrun. As explained earlier, potential engineering phase cost overrun indicators which are statistically significant and have a correlation strength of higher 0.25 or less than -0.25 are selected and presented. The same color coding rules ranging from red to light blue which were previously explained, are also applied to the values in Table 3.

Table 3. Correlations between project characteristics and engineering/design phase cost overrun

Engineering/Design Phase Cost Overrun		
	Correlation	**P-value**
Project Total Cost Performance	-0.32	0.036*
Project Total Cost Overrun	0.53	0.000**
Project primary Nature	-0.28	0.061
Frequency of Workarounds - Unavailability of Materials	0.33	0.029*
Delay in Delivery of Permanent Facility Equipment	0.39	0.009**
Industry Type	-0.33	0.028*
Project Documents Translated into a Different Language	-0.35	0.020*
Percentage of Modularization (offsite Construction)	0.30	0.045*
Clarity of Projects Scope During Designer/Contractor Selection	0.27	0.081
Alignment Quality of Internal Stakeholders	0.31	0.038*
Contract Containing Penalties for late completion	-0.41	0.005**
Contract Containing Liquidated damages:	-0.37	0.014*
Construction Phase Baseline Schedule	-0.29	0.056
Engineering/Design Phase Baseline Schedule	-0.30	0.046*
Project Baseline Schedule	-0.31	0.043*
Project Cost and Schedule Performance	-0.32	0.035*
Project Engineering Schedule Performance	-0.28	0.070
Project Engineering Cost Performance	-0.72	0.000**
Project Construction Schedule Performance	-0.31	0.044*
Project Construction Cost Performance	-0.32	0.032*
Construction Phase Cost Overrun	0.33	0.027*

Table 4 shows the strength and significance of the correlation between project characteristics and procurement phase cost overrun. The same color coding rules ranging from red to light blue which were previously explained, are also applied to the statistically significant indicators with the strength of more than 0.25 and/or less than -0.25.

Table 4. Correlations between project characteristics and procurement phase cost overrun

Procurement Phase Cost Overrun		
	Correlation	**P-value**
Project Total Schedule Performance	-0.37	0.013*
Project Total Cost Performance	-0.51	0.000**
Project Total Cost Overrun	0.48	0.001**
Procurement Phase Cost	0.26	0.084
Companys Familiarity with Technologies Involved in Construction phase	0.27	0.081
Number of Execution Locations-Procurement Phase	0.25	0.098
Number of Execution Locations-Engineering/Design Phase	0.27	0.074
Number of Countries Involved in Engineering/Design Phase	-0.47	0.001**
Communication Effectiveness within Owners Group	0.39	0.009**
Number of Permitting Agency Organizations	-0.73	0.000**
Number of Contractor Project Management Leadership Team Members	-0.52	0.000**
Number of Designer/Engineer Organizations	0.29	0.060
Impact of Project Economics on Obtaining Funding	0.31	0.041*
Number of External (Regulatory) Agencies Required to Approve Design	-0.47	0.001**
Number of Sponsoring Entities (Owners)	-0.51	0.000**
Number of Decision Making Entities Above PMT-Project Execution Plan	-0.40	0.006**
Number of Active External Stakeholders in Decision Making Process	-0.49	0.001**
Project Management Team Experience -Procurement Phase	0.29	0.059
Number of Contractor Driven Change Orders-Construction Phase	-0.49	0.001**
Number of Engineering Driven Change Orders-Construction Phase	-0.59	0.000**
Value of Owner Driven Change Orders-Engineering/Design Phase	0.26	0.093
Number of Owner Driven Change Orders	-0.35	0.021*
Project Procurement Schedule Performance	-0.36	0.016*
Procurement Phase Schedule Overrun	0.39	0.009**
Project Procurement Cost Performance	-0.29	0.060
Project Cost and Schedule Performance	-0.57	0.000**
Project Engineering Cost Performance	-0.39	0.009**
Total Engineering Phase Change Orders	0.28	0.061

The correlation strength of the significant construction phase indicators are shown in Table 5. The same color coding rules ranging from red to light blue which were previously explained, are also applied to the values in Table 5.

Table 5. Correlations between project characteristics and construction phase cost overrun

Construction Phase Cost Overrun	Correlation	P-value
Project Total Cost Performance	-0.40	0.007**
Project Total Cost Overrun	0.73	0.000**
Total Change Orders	0.29	0.060
Total Owner Driven Change Orders	0.28	0.065
Degree of Additional Quality Requirements - Construction Specifications	0.31	0.044*
Percentage of PM Staff Turnover	0.28	0.065
Project primary Nature	-0.26	0.083
Frequency of Workarounds - Unavailability of Materials	0.37	0.014*
Delay in Delivery of Permanent Facility Equipment	0.46	0.002**
Difficulty in System Design and Integration	0.42	0.005**
Percentage of Modularization (offsite Construction)	0.26	0.092
Impact of Project Location on Project Execution Plan	0.32	0.034*
Project Infrastructure Level Existed at the Site	0.28	0.064
Project Population Density	-0.28	0.069
Impact of Request for Information (RFI) on Project Design	0.36	0.015*
Change Management Process Effectiveness in Controlling Cost and Schedule	0.34	0.025*
Design Percentage Completion Prior to Project Budget Authorization	-0.33	0.028*
Clarity of Projects Scope During Designer/Contractor Selection	0.26	0.088
Number of Subcontractor Organizations	0.28	0.066
Impact of Required Inspection by External Agencies	0.28	0.071
Project Management Team Peak Size-Construction Phase	0.26	0.093
Construction Contract Type	0.33	0.026*
Engineering/Design Contract Type	0.37	0.015*
Value of Owner Driven Change Orders-Engineering/Design Phase	0.28	0.064
Project Procurement Schedule Performance	-0.32	0.032*
Procurement Phase Schedule Overrun	0.31	0.037*
Project Cost and Schedule Performance	-0.38	0.012*
Construction Phase Change Orders Cost Compare to Total Construction Cost	-0.38	0.012*
Engineering/Design Phase Schedule Overrun	0.26	0.090
Engineering/Design Phase Cost Overrun	0.33	0.027*
Project Construction Cost Performance	-0.64	0.000**
Total Engineering Phase Change Orders	0.30	0.051

Table 6 shows the outcome of the correlation analysis between project characteristics and project total schedule overrun. The same color coding of red-orange-green and light blue represents the strength of the significant schedule overrun indicators. Table 7 shows the result of the correlation analysis between project independent variables and engineering phase schedule overrun. The same color coding rules ranging from red to light blue is applied to the statistically significant engineering phase schedule phase overrun.

Table 6. Correlations between project characteristics and project schedule overrun

Project Schedule Overrun		
	Correlation	**P-value**
Project Total Schedule Performance	-0.30	0.049*
Project Total Cost Overrun	0.27	0.075
Percentage of PM Staff Turnover	0.26	0.090
Delay in Delivery of Permanent Facility Equipment	0.41	0.006**
Companys Familiarity with Technologies Involved in Engineering/Design phase	-0.25	0.100
Impact of Project Location on Project Execution Plan	0.27	0.074
Change Management Process Effectiveness in Controlling Cost and Schedule	0.34	0.023*
Impact of Change Orders Magnitude	0.27	0.080
Impact of Change Orders Timing	0.41	0.006**
Clarity of Projects Scope During Designer/Contractor Selection	0.38	0.012*
Previous Collaboration Between Designer/Engineer and Contractor	-0.39	0.008**
Communication Effectiveness within Contractors Group	0.33	0.030*
Communication Effectiveness within Designers/Engineers Group	0.33	0.027*
Number of Subcontractor Organizations	0.26	0.094
Company Revenue	-0.35	0.020*
Clarity of Owners Project Goals and Objectives	0.33	0.027*
Project Management Team Average Size-Engineering/Design Phase	0.37	0.015*
Project Management Team Peak Size-Engineering/Design Phase	0.36	0.015*
Construction Phase Actual Schedule	0.41	0.006**
Engineering/Design Phase Actual Schedule	0.61	0.000**
Project Actual Schedule	0.46	0.002**
Procurement Phase Schedule Overrun	0.37	0.014*
Project Cost and Schedule Performance	-0.26	0.089
Project Engineering Schedule Performance	-0.43	0.004**
Engineering/Design Phase Schedule Overrun	0.71	0.000**
Project Construction Schedule Performance	-0.55	0.000**
Construction Phase Schedule Overrun	0.91	0.000**

Table 7. Correlations between project characteristics and engineering/design phase schedule overrun

Engineering/Design Phase Schedule Overrun	Correlation	P-value
Project Schedule Overrun	0.71	0.000**
Project Total Cost Overrun	0.31	0.041*
Total Engineering Driven Change Orders	0.35	0.019*
Field Craft Labor Quality Issues	0.26	0.087
Delay in Delivery of Permanent Facility Equipment	0.33	0.029*
Difficulty in System Design and Integration	0.35	0.019*
Change Management Process Effectiveness in Controlling Cost and Schedule	0.48	0.001**
Impact of Change Orders Magnitude	0.33	0.029*
Impact of Change Orders Timing	0.44	0.003**
Clarity of Projects Scope During Designer/Contractor Selection	0.41	0.006**
Communication Effectiveness within Contractors Group	0.28	0.070
Communication Effectiveness within Designers/Engineers Group	0.46	0.002**
Communication Effectiveness within Owners Group	0.34	0.025*
Number of Subcontractor Organizations	0.56	0.000**
Number of Designer/Engineer Organizations	0.36	0.017*
Number of Owner Organizations	0.26	0.086
Clarity of Funding Process during Front End Planning	0.33	0.031*
Project Funding Delays	0.35	0.019*
Number of Financial Approval Authority Thresholds	0.53	0.000**
Impact of Required Inspection by External Agencies	0.30	0.052
Clarity of Owners Project Goals and Objectives	0.34	0.024*
Alignment Quality of Internal Stakeholders	0.26	0.089
Construction Phase Actual Schedule	0.31	0.039*
Engineering/Design Phase Actual Schedule	0.38	0.010*
Project Actual Schedule	0.33	0.030*
Value of Engineering Driven Change Orders-Construction Phase	0.31	0.043*
Value of Owner Driven Change Orders	0.28	0.065
Procurement Phase Schedule Overrun	0.33	0.029*
Engineering Phase Change Orders Cost Compare to Total Engineering Cost	0.49	0.001**
Project Engineering Schedule Performance	-0.49	0.001**
Project Construction Schedule Performance	-0.35	0.019*
Construction Phase Schedule Overrun	0.52	0.000**
Construction Phase Cost Overrun	0.26	0.090
Total Construction Phase Change Orders	0.26	0.084

Table 8 shows the results of the correlation analysis between project characteristics and procurement phase schedule overrun. Again, the same color coding rules have been applied to the strength correlation value in this table.

Table 8. Correlations between project characteristics and procurement phase schedule overrun

Procurement Phase Schedule Overrun		
	Correlation	**P-value**
Project Total Schedule Performance	-0.33	0.027*
Project Schedule Overrun	0.37	0.014*
Project Total Cost Performance	-0.42	0.004**
Project Total Cost Overrun	0.40	0.008**
Procurement Phase Cost	0.38	0.011*
Procurement Phase Budget	0.38	0.010*
Project Total Cost	0.30	0.051
Project Total Budget	0.30	0.051
Percentage of Craft Labor Turnover	0.29	0.059
Bulk Materials Quality Issues	0.38	0.012*
Field Craft Labor Quality Issues	0.34	0.024*
Number of New Systems Tied into Existing Systems	0.29	0.057
Difficulty in System Design and Integration	0.51	0.000**
Number of Execution Locations-Procurement Phase	0.49	0.001**
Impact of Project Location on Project Execution Plan	0.34	0.025*
Impact of Request for Information (RFI) on Project Design	0.43	0.004**
Change Management Process Effectiveness in Controlling Cost and Schedule	0.28	0.066
Clarity of Change Management Process	0.32	0.033*
Project Scope Similarity Level at Completion Compared to Authorization	0.30	0.051
Impact of Change Orders Magnitude	0.33	0.030*
Impact of Change Orders Timing	0.29	0.060
Design Percentage Completion Prior to Project Budget Authorization	-0.33	0.028*
Previous Collaboration Between Designer/Engineer and Contractor	-0.28	0.064
Previous Collaboration Between Owner and Designer/Engineer	-0.28	0.068
Number of Subcontractor Organizations	0.25	0.099
Number of Designer/Engineer Organizations	0.40	0.008**
Number of Funding Phases	0.30	0.046*
Number of Joint Venture Partners (Contractors)	0.36	0.016*
Number of Change Order Approval Above PM	0.32	0.035*
Impact of Required Inspection by External Agencies	0.30	0.051
Project Management Team Average Size-Construction Phase	0.33	0.030*
Project Management Team Peak Size-Construction Phase	0.33	0.026*
Project Management Team Peak Size-Procurement Phase	0.28	0.065
Project Management Team Average Size-Engineering/Design Phase	0.41	0.006**
Project Management Team Peak Size-Engineering/Design Phase	0.36	0.015*
Value of Engineering Driven Change Orders-Engineering/Design Phase	0.26	0.090
Project Procurement Schedule Performance	-0.73	0.000**
Project Procurement Cost Performance	-0.30	0.051
Procurement Phase Cost Overrun	0.39	0.009**
Project Cost and Schedule Performance	-0.49	0.001**
Project Engineering Schedule Performance	-0.42	0.004**
Engineering/Design Phase Schedule Overrun	0.33	0.029*
Project Construction Cost Performance	-0.40	0.007**
Construction Phase Cost Overrun	0.31	0.037*

Table 9 shows the strength of the significant project characteristics which are correlated (correlation value of more than 0.25 or less than -0.25) with the construction phase schedule overrun. The same color coding rules which were explained earlier in this Chapter, were also applied to the values in Table 9.

Table 9. Correlations between project characteristics and construction phase schedule overrun

Construction Phase Schedule Overrun	Correlation	P-value
Project Schedule Overrun	0.91	0.000**
Delay in Delivery of Permanent Facility Equipment	0.38	0.011*
Project Population Density	0.28	0.069
Impact of Change Orders Timing	0.38	0.011*
Clarity of Projects Scope During Designer/Contractor Selection	0.30	0.046*
Previous Collaboration Between Designer/Engineer and Contractor	-0.35	0.019*
Company Revenue	-0.29	0.060
Project Delivery Method	0.27	0.071
Construction Phase Actual Schedule	0.39	0.009**
Engineering/Design Phase Actual Schedule	0.61	0.000**
Project Actual Schedule	0.39	0.009**
Project Engineering Schedule Performance	-0.29	0.056
Engineering/Design Phase Schedule Overrun	0.52	0.000**
Project Construction Schedule Performance	-0.57	0.000**

5.4 Test of Statistical Significance

Depending on the type of data used in this study, the method of analysis differs. This is due to the fact that there are different assumptions and limitations to the statistical analysis tests. Table 10 summarizes the basic formal statistical methods that were used for data analysis in this research. This table includes information about each of the statistical tests, the null hypothesis and alternative hypothesis for each test, and the corresponding assumptions. P-values that indicated the statistical significance of differences between the two groups (phase-based good cost/schedule performance vs. poor cost/schedule performance) were generated through the following relevant tests.

Table 10. Statistical analysis methods

Statistical Test	Null/Alternative Hypothesis	Assumptions
Two-Sample T-Test (Adjusted R-Squared): This test was used where the response is a count or numerical value.	*Null Hypothesis*: The means for good cost/schedule performance and poor cost/schedule performance are the same. *Alternative Hypothesis:* The means for good cost/schedule performance and poor cost/schedule performance are the same.	The two groups (good cost/schedule performance and poor cost/schedule performance) follow a normal distribution. Each project was independent from other projects.
Kruskal-Wallis/Wilcoxon Test: This test was used for likert data (ordinal scale), where it could not necessarily be assumed that the data follows a normal distribution.	*Null Hypothesis:* The probability that median of good cost/schedule performance is greater than median of poor cost/schedule performance on this question is 0.5 (The distributions are the same). *Alternative Hypothesis:* The probability that median of good cost/schedule performance is greater than median of poor cost/schedule performance on this question is not equal to 0.5 (The distributions are not the same).	The two groups follow an identically scaled distribution. Each project was independent of other projects.
Chi-Squared Test (Nagelkerke's R-Squared): This test was used for survey questions with binary responses ("Yes" or "No" response), testing whether the observed frequencies of "Yes" or "No" are equal for both good cost/schedule performance and poor cost/schedule performance.	*Null Hypothesis:* The observed frequencies of "Yes" and "No" for good cost/schedule performance are not different from those for good cost/schedule performance. *Alternative Hypothesis:* The observed frequencies of "Yes" and "No" for good cost/schedule performance are different from those for good cost/schedule performance.	Each project was independent of other projects

Table 11 shows the results of the two sample t-test to identify which ones of the continuous independent project variables are statistically significant in differentiating between good and poor cost and schedule performance during engineering/design, procurement and construction phases. This table presents the significance level (p-value) of each of the project independent variables in differentiating between phase-based good and poor cost and schedule performances. As explained before, the acceptable significance level (p-value) has been increased from 0.05 to 0.1 to include a greater number of variables in the next screening phase. In this table, those variables which have p-values of less than 0.05 are highlighted in pink and those project characteristics with p-values between 0.05 and 0.1 are highlighted in purple. It should be noted that project characteristics with p-values of less than 0.1 are sent to the next variable reduction step (sequential variable reduction).

Table 12 shows the results of the Kruskal-Wallis test to identify categorical independent project characteristics which are statistically significant in differentiating between good and poor cost and schedule performance during engineering/design, procurement and construction phases. For consistency, the same rules for highlighting the significance level of the variables in pink and purple for differencing between good and poor cost and schedule performance are also applied to the values in this table.

The outcome of the Chi-Squared test to identify binary variables which differentiate between good and poor cost and schedule performance are presented in Table 13. Again, the same color coding rules for the significance level of the independent project variables are also applied to the values in this table.

Table 11. Two sample T-test statistical significance for cost and schedule overrun

Two Sample T-Test	Project Total Cost Performance	Project Engineering Cost Performance	Project Procurement Cost Performance	Project Construction Cost Performance	Project Total Schedule Performance	Project Engineering Schedule Performance	Project Procurement Schedule Performance	Project Construction Schedule Performance	Project Cost and Schedule Performance
Project Total Budget	0.10	0.56	0.16	0.17	0.24	0.26	0.11	0.33	0.66
Project Total Cost	0.09	0.51	0.14	0.16	0.25	0.26	0.11	0.34	0.66
Project Total Cost Overrun	0.00	0.02	0.16	0.00	0.12	0.11	0.00	0.08	0.00
Engineering/Design Phase Budget	0.22	0.35	0.09	0.22	0.17	0.35	0.18	0.45	0.47
Engineering/Design Phase Cost	0.22	0.31	0.09	0.22	0.17	0.35	0.19	0.42	0.48
Engineering/Design Phase Cost Overrun	0.04	0.00	0.26	0.03	0.26	0.07	0.24	0.04	0.11
Procurement Phase Budget	0.25	0.67	0.00	0.07	0.11	0.23	0.20	0.65	0.84
Procurement Phase Cost	0.24	0.64	0.00	0.07	0.10	0.23	0.21	0.65	0.85
Procurement Phase Cost Overrun	0.01	0.19	0.00	0.01	0.71	0.55	0.50	0.84	0.13
Construction Phase Budget	0.12	0.41	0.16	0.11	0.31	0.18	0.07	0.27	0.61
Construction Phase Cost	0.11	0.42	0.13	0.08	0.31	0.18	0.07	0.32	0.62
Construction Phase Cost Overrun	0.01	0.60	0.22	0.00	0.26	0.49	0.03	0.48	0.04
Number of Owner Driven Change Orders-Engineering/Design Phase	0.75	0.09	0.74	0.48	0.91	0.94	0.88	0.65	0.96
Number of Owner Driven Change Orders	0.37	0.28	0.56	0.39	0.17	0.50	0.26	0.48	0.21
Value of Owner Driven Change Orders-Engineering/Design Phase	0.63	0.31	0.83	0.53	0.59	0.18	0.26	0.22	0.59
Value of Owner Driven Change Orders	0.85	0.30	0.69	0.61	0.96	0.85	0.37	0.75	0.98
Number of Engineering Driven Change Orders-Engineering/Design Phase	0.34	0.64	0.37	0.51	0.17	0.77	0.35	0.63	0.25
Number of Engineering Driven Change Orders-Construction Phase	0.09	0.14	0.90	0.43	0.01	0.35	0.07	0.77	0.01
Value of Engineering Driven Change Orders-Engineering/Design Phase	0.12	0.34	0.12	0.21	0.94	0.64	0.13	0.59	0.50
Value of Engineering Driven Change Orders-Construction Phase	0.75	0.20	1.00	0.49	0.73	0.55	0.99	0.85	1.00
Number of Contractor Driven Change Orders-Engineering/Design Phase	1.00	0.34	0.32	0.57	0.17	0.82	0.47	0.50	0.61
Number of Contractor Driven Change Orders-Construction Phase	0.10	0.31	0.56	0.14	0.16	0.29	0.46	0.55	0.13
Value of Contractor Driven Change Orders-Engineering/Design Phase	0.52	0.35	0.31	0.89	0.22	0.67	0.59	0.53	0.57
Value of Contractor Driven Change Orders-Construction Phase	0.86	0.33	0.14	0.98	0.05	0.67	0.03	0.83	0.20
Project Baseline Schedule	0.59	0.00	0.94	0.92	0.48	0.17	0.26	0.09	0.69
Project Actual Schedule	0.91	0.00	0.99	0.87	0.50	0.14	0.05	0.19	0.90
Project Schedule Overrun	0.11	0.81	0.85	0.35	0.00	0.22	0.00	0.62	0.00
Engineering/Design Phase Baseline Schedule	0.23	0.11	0.04	0.31	0.32	0.41	0.77	0.83	0.36
Engineering/Design Phase Actual Schedule	0.42	0.28	0.13	0.65	0.89	0.02	0.97	0.24	0.78
Engineering/Design Phase Schedule Overrun	0.22	0.30	0.40	0.11	0.22	0.00	0.16	0.02	0.29
Procurement Phase Baseline Schedule	0.69	0.35	0.28	0.38	0.68	0.63	0.88	0.19	0.57
Procurement Phase Actual Schedule	0.18	0.58	0.67	0.07	0.87	0.18	0.17	0.57	0.47
Procurement Phase Schedule Overrun	0.00	0.93	0.05	0.01	0.03	0.00	0.00	0.14	0.00
Construction Phase Baseline Schedule	0.61	0.15	0.43	0.21	0.87	0.13	0.37	0.03	0.60
Construction Phase Actual Schedule	0.69	0.35	0.83	0.49	0.49	0.01	0.37	0.63	0.79

Table 11. Continued

Two Sample T-Test	Project Total Cost Performance	Project Engineering Cost Performance	Project Procurement Cost Performance	Project Construction Cost Performance	Project Total Schedule Performance	Project Engineering Schedule Performance	Project Procurement Schedule Performance	Project Construction Schedule Performance	Project Cost and Schedule Performance
Construction Phase Schedule Overrun	0.83	0.63	0.22	0.72	0.31	0.06	1.00	0.00	0.53
Project Management Team Peak Size-Engineering/Design Phase	0.61	0.35	0.49	0.19	0.15	0.08	0.03	0.11	0.17
Project Management Team Average Size-Engineering/Design Phase	0.61	0.55	0.50	0.12	0.20	0.11	0.02	0.16	0.26
Project Management Team Experience -Engineering/Design Phase	0.43	0.44	0.46	0.29	0.51	0.83	0.72	0.55	0.47
Project Management Team Peak Size-Procurement Phase	0.66	0.34	0.67	0.06	0.88	0.07	0.14	0.31	0.55
Project Management Team Average Size-Procurement Phase	0.97	0.52	0.80	0.08	0.91	0.13	0.17	0.32	0.74
Project Management Team Experience -Procurement Phase	0.84	0.61	0.18	0.24	0.41	0.53	0.27	0.78	0.48
Project Management Team Peak Size-Construction Phase	0.08	0.67	0.63	0.06	0.25	0.48	0.01	0.58	0.18
Project Management Team Average Size-Construction Phase	0.22	0.52	0.57	0.09	0.35	0.58	0.01	0.61	0.38
Project Management Team Experience -Construction Phase	0.43	0.33	0.45	0.34	0.42	0.63	0.62	0.75	0.64
Number of Active Internal Stakeholders in Decision Making Process	0.27	0.83	0.20	0.02	0.53	0.11	0.31	0.57	0.32
Number of Active External Stakeholders in Decision Making Process	0.58	0.13	0.25	0.78	0.19	0.41	0.45	0.46	0.10
Number of Decision Making Entities Above PMT-Project Execution Plan	0.27	0.53	0.02	0.52	0.46	0.94	0.77	0.59	0.26
Number of Financial Approval Authority Thresholds	0.06	0.04	0.03	0.05	0.41	0.02	0.08	0.65	0.02
Maximum Number of Authority Levels Above PM-Change Order Approval	0.94	0.76	0.02	0.52	0.13	0.30	0.98	0.76	0.24
Number of Change Order Approval Above PM	0.47	0.16	0.49	0.82	0.79	0.31	0.34	0.41	0.85
Number of Sponsoring Entities (Owners)	0.41	0.10	0.24	0.22	0.01	0.36	0.39	0.55	0.02
Number of Joint Venture Partners (Contractors)	0.15	0.21	0.82	0.16	0.05	0.08	0.00	0.72	0.08
Number of Status Reports by Project team in Six Months	0.43	0.08	0.64	0.87	0.39	0.96	0.91	0.87	0.51
Number of Required Total Permits	0.55	0.14	0.43	0.58	0.41	0.06	0.86	0.17	0.71
Number of External (Regulatory) Agencies Required to Approve Design	0.50	0.07	0.57	0.11	0.15	0.88	0.15	0.53	0.09
Number of Funding Phases	0.39	0.87	0.76	0.30	0.50	0.05	0.02	0.76	0.56
Number of Owner Organizations	0.73	0.71	0.63	0.74	0.54	0.75	0.67	0.18	0.73
Number of Owner Project Management Leadership Team Members	0.83	0.80	0.02	0.07	0.44	0.95	0.82	0.59	0.38
Number of Designer/Engineer Organizations	0.26	0.78	0.14	0.33	0.38	0.69	0.21	0.09	0.43
Number of Designer/Engineer Project Management Leadership Team Members	0.59	0.66	0.04	0.10	0.42	0.58	0.71	0.80	0.49
Number of Contractor Organizations	0.24	0.41	0.60	0.51	0.56	0.45	0.38	0.26	0.50
Number of Contractor Project Management Leadership Team Members	0.28	0.33	0.01	0.23	0.08	0.86	0.16	0.39	0.04
Number of Subcontractor Organizations	0.40	0.49	0.52	0.22	0.46	0.01	0.11	0.35	0.37
Number of Subcontractor Project Management Leadership Team Members	0.24	0.16	0.37	0.66	0.98	0.74	0.71	0.60	0.74
Number of Vendor Organizations	0.23	0.35	0.17	0.06	0.30	0.04	0.27	0.37	0.48
Number of Vendor Project Management Leadership Team Members	0.31	0.05	0.53	0.79	0.92	0.90	0.77	0.50	0.82
Number of Permitting Agency Organizations	0.09	0.06	0.14	0.66	0.00	0.82	0.04	0.55	0.00
Number of Permitting Agency Project Management Leadership Team Members	0.31	0.28	0.87	0.32	0.74	0.54	0.81	0.71	0.88

Table 11. Continued

Two Sample T-Test	Project Total Cost Performance	Project Engineering Cost Performance	Project Procurement Cost Performance	Project Construction Cost Performance	Project Total Schedule Performance	Project Engineering Schedule Performance	Project Procurement Schedule Performance	Project Construction Schedule Performance	Project Cost and Schedule Performance
Number of Countries Involved in Engineering/Design Phase	0.47	0.21	0.07	0.08	0.01	0.28	0.30	0.68	0.03
Number of Countries Involved in Construction Phase	0.66	0.10	0.30	0.05	0.40	0.97	0.41	0.25	0.46
Number of Execution Locations-Engineering/Design Phase	0.32	1.00	0.58	0.13	0.78	1.00	0.31	0.80	0.58
Number of Execution Locations-Procurement Phase	0.39	0.72	0.13	0.21	0.58	0.45	0.01	0.85	0.09
Number of Execution Locations-Construction Phase	0.69	0.32	0.74	0.15	0.20	0.21	0.81	0.43	0.42
Number of New Systems Tied into Existing Systems	0.12	0.61	0.89	0.28	0.75	0.19	0.14	0.46	0.47
Planned Percentage of Engineering/Design Completion at the Start of Construction	0.51	0.03	0.15	0.81	0.81	0.01	0.63	0.61	0.82
Actual Percentage of Engineering/Design Completion at the Start of Construction	0.10	0.33	0.90	0.22	0.82	0.23	0.14	0.15	0.41

Table 12. Kruskal-Wallis statistical significance test for categorical variables for cost and schedule overrun

Kruskal-wallis Test on Categorical Variables	Project Total Cost Performance	Project Engineering Cost Performance	Project Procurement Cost Performance	Project Construction Cost Performance	Project Total Schedule Performance	Project Engineering Schedule Performance	Project Procurement Schedule Performance	Project Construction Schedule Performance	Project Cost and Schedule Performance
Project Complexity Level	0.72	0.09	0.01	0.03	0.27	0.88	0.12	0.06	0.84
Project Complexity Level Compare to other Company's Projects	0.36	0.44	0.03	0.26	0.40	0.95	0.68	0.08	0.26
Company Revenue	0.11	0.82	0.25	0.30	0.43	0.70	1.00	0.17	0.48
Industry Type	0.50	0.47	0.37	0.53	0.95	0.71	0.81	0.40	0.85
Project primary Nature	0.05	0.30	0.74	0.01	0.15	0.16	0.26	0.69	0.07
Project Execution Driver	0.05	0.03	0.59	0.81	0.58	0.06	0.33	0.47	0.24
Project Business Driver	0.18	0.08	0.28	0.86	0.06	0.37	0.28	0.14	0.12
Project Delivery Method	0.43	0.37	0.99	0.85	0.26	0.63	0.91	0.43	0.48
Project Influence on Organization's Success	0.49	0.10	0.21	0.18	0.30	0.26	0.83	0.53	0.46
Alignment Quality of Internal Stakeholders	0.51	0.18	0.13	0.10	0.87	0.06	0.61	0.66	0.70
Alignment Quality of External Stakeholders	0.10	0.94	0.64	0.89	0.68	0.67	0.18	0.97	0.27
Clarity of Owner's Project Goals and Objectives	0.99	0.55	0.48	0.38	0.06	0.00	0.10	0.12	0.39
Impact of Required Approvals-Internal Stakeholders	0.91	0.92	0.08	0.56	0.12	0.30	0.24	0.91	0.39
Impact of Required Approvals-External Stakeholders	0.41	0.12	0.01	0.28	0.98	0.72	0.82	0.25	0.85
Impact of Required Inspection by External Agencies	0.74	0.75	0.09	0.13	0.65	0.32	0.65	0.86	0.48
Difficulty Level in Obtaining Permits	0.92	0.62	0.34	0.73	0.52	0.51	0.86	0.37	0.86
Difficulty Level in Obtaining Design Approvals	0.65	0.55	0.13	0.09	0.21	0.11	0.46	0.81	0.46
Impact of External Agencies on Project Execution plan	0.34	0.25	0.19	0.14	0.88	0.19	0.85	0.98	0.35
Clarity of Funding Process during Front End Planning	1.00	0.59	0.09	0.77	0.18	0.32	0.56	0.68	0.33
Communication Effectiveness within Owner's Group	0.87	0.29	0.17	0.45	0.18	0.62	0.79	0.73	0.08
Communication Effectiveness within Designer's/Engineer's Group	0.80	0.19	0.85	0.09	0.82	0.00	0.48	0.03	0.94
Communication Effectiveness within Contractor's Group	0.83	0.85	0.81	0.04	0.39	0.02	0.70	0.10	0.32
Communication Effectiveness between Subcontractor's and contractor's Group	0.52	0.46	0.99	0.07	0.83	0.02	0.33	0.39	0.81
Communication Effectiveness between Vendor's and Subcontractor's/contractor	0.20	0.92	0.31	0.40	0.44	0.33	0.56	0.23	0.33
Communication Effectiveness within Permitting Agencies Group	0.13	0.86	0.99	0.65	0.59	0.03	0.79	0.69	0.27
Clarity of Project's Scope During Designer/Contractor Selection	0.84	0.33	0.31	0.27	0.22	0.09	0.75	0.10	0.68
Design Percentage Completion Prior to Project Budget Authorization	0.18	0.17	0.10	0.06	0.44	0.18	0.02	0.58	0.29
Impact of Change Orders' Timing	0.77	0.88	0.54	0.44	0.67	0.07	0.24	0.10	0.44
Impact of Change Orders' Magnitude	0.94	0.89	0.09	0.19	0.79	0.07	0.28	0.46	0.51
Project Scope Similarity Level at Completion Compared to Authorization	0.83	0.73	0.13	0.20	0.85	0.00	0.54	0.52	0.81
Clarity of Change Management Process	0.48	0.25	0.55	0.27	0.16	0.05	0.23	0.80	0.44
Change Management Process Followed by Key Project Team Members	0.08	0.76	0.30	0.30	0.84	0.32	0.65	0.54	0.56
Change Management Process Effectiveness in Controlling Cost and Schedule	0.68	0.48	0.62	0.06	0.10	0.11	0.09	0.17	0.15
Impact of Request for Information (RFI) on Project Design	0.31	0.52	0.38	0.00	0.97	0.02	0.06	0.16	0.77
Project Remoteness	0.30	0.67	0.32	0.06	0.75	0.33	0.69	0.73	0.39

Table 12. Continued

Kruskal-wallis Test on Categorical Variables	Project Total Cost Performance	Project Engineering Cost Performance	Project Procurement Cost Performance	Project Construction Cost Performance	Project Total Schedule Performance	Project Engineering Schedule Performance	Project Procurement Schedule Performance	Project Construction Schedule Performance	Project Cost and Schedule Performance
Project Population Density	0.07	0.37	0.12	0.09	0.09	0.88	0.21	0.77	0.05
Project Infrastructure Level Existed at the Site	0.25	0.49	0.41	0.01	0.87	0.65	0.93	0.23	0.35
Impact of Project Location on Project Execution Plan	0.86	0.57	0.25	0.08	0.22	0.32	0.36	0.43	0.83
Percentage of Modularization (offsite Construction)	0.29	0.35	0.51	0.58	0.40	0.60	0.94	0.68	0.46
Security Requirements for Accessing Project Construction Site	0.99	0.46	0.35	0.38	0.21	0.64	0.76	0.97	0.76
Company's Familiarity with Technologies Involved in Engineering/Design phase	0.92	0.67	0.12	0.49	0.24	0.78	0.82	0.04	0.74
Company's Familiarity with Technologies Involved in Construction phase	0.80	0.70	0.02	0.20	0.35	0.67	0.78	0.09	0.87
Company's Familiarity with Technologies Involved in Operation phase	0.46	0.64	0.03	0.11	0.46	0.67	0.36	0.23	0.82
Difficulty in System Design and Integration	0.09	0.36	0.02	0.02	0.99	0.02	0.06	0.59	0.51
Actual Percentage of PM Staff compared to planned PM Staff	0.66	0.56	0.62	0.37	0.31	0.23	0.29	0.12	0.50
Actual Percentage of field craft labor compared to planned field craft labor-pea	0.77	0.88	0.20	0.61	0.11	0.77	0.31	0.75	0.15
Actual Percentage of Personnel Availability Compared to Project Plan	0.50	0.22	0.89	0.07	0.04	0.78	0.76	0.32	0.67
Delay in Delivery of Permanent Facility Equipment	0.37	0.25	0.48	0.05	0.02	0.08	0.17	0.10	0.08
Frequency of Workarounds - Unavailability of Materials	0.12	0.33	0.02	0.03	0.64	0.44	0.23	0.63	0.73
Field Craft Labor Quality Issues	0.32	0.43	0.05	0.19	0.49	0.07	0.13	0.91	0.56
Bulk Materials Quality Issues	0.20	0.51	0.05	0.12	0.37	0.31	0.07	0.46	0.27
Permanent Equipment Quality Issues	0.12	0.10	0.76	0.83	0.69	0.92	0.53	0.05	0.68
Percentage of Craft Labor Turnover	0.76	0.87	0.79	0.01	0.14	0.08	0.14	0.86	0.50
Percentage of PM Staff Turnover	0.38	0.82	0.70	0.23	0.06	0.05	0.36	0.71	0.59
Percentage of Bulk Materials Sourced Locally - Within Project Country	0.60	0.82	0.40	0.01	0.48	0.51	0.55	0.59	0.21
Percentage of Permanent Equipment Sourced Locally - Within Project Country	0.52	0.89	0.99	0.05	0.13	0.56	0.43	0.66	0.19
Percentage of Craft Labor Sourced Locally	0.07	0.71	0.56	0.01	0.48	0.30	0.01	0.66	0.14
Reuse of Existing Installed Equipment	0.48	0.07	0.64	0.04	0.12	0.66	0.91	0.67	0.38
Degree of Additional Quality Requirements - Construction Specifications	0.55	0.48	0.27	0.02	0.97	0.24	0.54	0.54	0.70
Degree of Additional Quality Requirements - Materials Specifications	0.45	0.81	0.35	0.07	0.28	0.68	0.84	0.29	0.25
Cost Target at Authorization Compared to Industry Benchmarks	0.92	0.14	0.28	0.15	0.59	0.15	0.11	0.27	0.41
Schedule Target at Authorization Compared to Industry Benchmarks	0.90	0.93	0.59	0.30	0.22	0.81	0.28	0.99	0.52
Constructability Implementation	0.15	0.37	0.76	0.58	0.41	0.00	0.91	0.70	0.20
Team Building Implementation	0.56	0.32	0.91	0.18	0.43	0.00	0.85	0.59	0.69
Alignment Process Implementation	0.79	0.08	0.72	0.02	0.15	0.00	0.10	0.66	0.43
Partnering Implementation	0.62	0.55	0.21	0.01	0.86	0.00	0.32	0.82	0.40
Front End Planning Process Implementation	0.34	0.48	0.13	0.06	0.01	0.12	0.68	0.21	0.09
Change Management Implementation	0.63	0.64	0.82	0.31	0.03	0.60	0.41	0.84	0.50
Materials Management Implementation	0.12	0.06	0.98	0.08	0.01	0.00	0.04	0.37	0.04

Table 12. Continued

Kruskal-wallis Test on Categorical Variables	Project Total Cost Performance	Project Engineering Cost Performance	Project Procurement Cost Performance	Project Construction Cost Performance	Project Total Schedule Performance	Project Engineering Schedule Performance	Project Procurement Schedule Performance	Project Construction Schedule Performance	Project Cost and Schedule Performance
Zero Accident Techniques Implementation	0.20	0.80	0.27	0.21	0.45	0.77	0.83	0.20	0.66
Planning for Start Up Implementation	0.54	0.12	0.79	0.78	0.04	0.05	0.10	0.47	0.26
Dispute Review Implementation	0.30	0.64	0.10	0.07	0.87	0.56	0.42	0.63	0.81
Quality Management Implementation	0.85	0.94	0.58	0.72	0.21	0.19	0.53	0.92	0.74
Lessons Learned Process Implementation	0.88	0.93	0.44	0.26	0.73	0.19	0.69	0.21	0.94
Risk Assessment Process Implementation	0.43	0.62	0.87	0.35	0.22	0.06	0.86	0.43	0.72

Table 13. Chi-Squared statistical significance test for binary variables for cost and schedule overrun

Chi-Squared Test of Binary Data	Project Total Cost Performance	Project Engineering Cost Performance	Project Procurement Cost Performance	Project Construction Cost Performance	Project Total Schedule Performance	Project Engineering Schedule Performance	Project Procurement Schedule Performance	Project Construction Schedule Performance	Project Cost and Schedule Performance
Contract Containing Liquidated damages:	0.13	0.01	0.50	0.54	0.30	1.00	0.54	0.13	0.80
Contract Containing Penalties for late completion	0.02	0.03	0.65	0.28	1.00	0.06	0.35	0.00	0.26
Contract Containing Early Completion Bonuses	0.33	0.83	0.70	0.41	0.28	0.65	0.60	0.20	0.59
Engineering/Design Contract Type	0.06	0.24	0.90	0.04	0.22	0.90	0.17	0.57	0.38
Procurement Contract Type	0.38	0.78	0.08	0.20	0.48	0.71	0.47	0.38	0.14
Construction Contract Type	0.22	0.55	0.39	0.14	0.38	0.62	0.14	0.55	0.33
Project Funding Delays	0.62	0.39	0.58	0.32	1.00	0.08	0.95	0.85	0.75
Impact of Project Economics on Obtaining Funding	0.34	0.47	0.66	0.45	0.77	0.64	0.20	0.25	0.57
Previous Collaboration Between Owner and Designer/Engineer	0.83	0.83	0.65	0.95	0.05	0.70	0.20	0.33	0.26
Previous Collaboration Between Owner and Contractor	0.52	0.52	0.87	0.62	0.37	0.30	0.83	0.52	0.82
Previous Collaboration Between Designer/Engineer and Contractor	0.89	0.60	0.25	0.55	0.09	0.06	0.38	0.03	0.51
Project Documents Translated into a Different Language	0.12	0.09	0.66	0.19	0.08	0.78	0.22	0.32	0.05

5.5 Summary

In this Chapter, the framework and details of the statistical methods used to analyze the data were discussed. Initially, the missing data points were generated through the mean value substitution and transformed to their corresponding *z*-values. Then, in order to screen and narrow down the number of cost and schedule performance indicators, several statistical tests have been performed. Depending on the type of the data, one of the two sample T-Test, Kruskal-Wallis or Chi-Squared was selected and performed. Also, the results of the correlation analysis between project characteristics and phase-based project cost and schedule overrun were presented. The outcome of these two analysis were combined and included in the sequential variable reduction. The output of this screening phase was used as an input for stepwise data reduction in order to further decrease the number of potential indicators. Next, construction experience was used to incorporate the excluded cost and schedule performance indicators, if it was believed that the variable should not have been excluded through the statistics. At the end, the all-possible combination regression was used to finalize the phase-based cost and schedule performance indicators. In next Chapter, the stepwise regression methodology is explained and used to further narrow down the number of phase-based cost and schedule overrun indicators.

6. STEPWISE REGRESSION DATA REDUCTION

Stepwise regression is a semi-automated process of building a model by successively adding or removing variables based solely on the t-statistics of their estimated coefficients (Abderrahmane et al., 2013). The goal of this method is to derive an equation that uses the best combination of independent (predictor) variables (that may or may not contain all of them) that best predict the dependent (predicted) variable.

In stepwise regression, predictor variables are introduced to the regression equation one at a time based upon certain statistical criteria. Essentially, at each step of the iterative process, the predictor variable that increases the coefficient of determination, R-squared, is entered into the prediction equation. The process of adding new variables to the equation is terminated when additional variables do not add anything statistically significant to the regression equation. Therefore, as stated earlier, it may be the case that not all predictor variables enter the equation in stepwise regression.

The outcome of stepwise variable reduction for each phase is presented in this Chapter. As explained earlier, in this study stepwise regression has not been utilized to develop final predictive models. Rather, it has been used to further reduce and narrow down the number of potential variables which impact project cost and schedule. For this reason, the cut-off p-value has been increased from 0.05 to 0.20 in order to have a larger pool of potential project performance determinants in the next step.

6.1 Stepwise Regression for Cost and Schedule Overrun

Table 14 shows the project schedule performance leading indicators based on stepwise regression variable reduction method. As results show, the highest number of potential schedule performance indicators in a single category was resulted from the "Interface" category which means that communication effectiveness and previous collaborations could have a significant impact on total project schedule overrun.

Table 14. Leading indicators for total schedule overrun

Category	Significant Variables	P-Level
General Characteristics	Project Management Team Average Size-Engineering/Design Phase	0.0187
	Contribution of PMT Members in Procurement Phase-Average Number of Participants	0.0683
Interfaces	Previous Collaboration Between Designer/Engineer and Contractor	0.0244
	Number of Subcontractor Organizations	0.0814
	Communication Effectiveness within Engineering/Designers Group	0.0144
Location	Project Population Density	0.0339
Resources	Delay in Delivery of Permanent Facility Equipment	0.0368
Scope Definition	Change Management Process Effectiveness in Controlling Cost and Schedule	0.0919
Best Practices	Front End Planning Process Implementation	0.0744

Cost performance leading indicators resulted from stepwise regression are listed in Table 15. According to these results, the "General Characteristics" of a project such as engineering/design phase contract type, project primary nature and contract penalties for late completion have the highest number of potential cost performance indicators in a single category. Based on the analysis, "Design and Technology" and "Resources" are the next two significant categories of cost performance determinants.

Table 15. Leading indicators for total cost overrun

Category	Significant Variables	P-Level
General Characteristics	Engineering/Design Contract Type	0.016
	Project primary Nature	0.033
	Contract Containing Penalties for late completion	0.077
Design & Technology	Difficulty in System Design and Integration	0.095
Interfaces	Number of Engineering/Design Entities (Single vs. Multiple)	0.017
Resources	Percentage of Craft Labor Sourced Locally	0.043
	Delay in Delivery of Permanent Facility Equipment	0.037
Scope Definition	Design Percentage Completion Prior to Project Budget Authorization	0.034
	Change Management Process Followed by Key Project Team Members	0.091
Stakeholder Management	Alignment Quality of Internal Stakeholders	0.056
Best Practices	Use of Partnering Strategy	0.071
	Planning for Start Up Implementation	0.075

6.2 Phase-Based Stepwise Regression for Schedule Overrun

Table 16 lists all potential variables affecting schedule performance during the design/engineering phase. As the results indicate, "Interface" category has the highest number of potential engineering phase schedule performance determinants in a single category. Based on these results, it is concluded that "communication effectiveness" and "previous collaboration between entities" are two major engineering phase schedule performance determinates.

Table 16. Leading indicators for schedule overrun in engineering phase

Category	Significant Variables	P-Level
General Characteristics	Project Management Team Peak Size-Procurement Phase	0.0161
	Project Management Team Peak Size-Engineering/Design Phase	0.0042
	Project Execution Driver	0.0453
	Procurement PMT Efficiency Level-Average Number of Participants	0.0521
	Contract Containing Penalties for late completion	0.0205
Execution Targets	Planned Percentage of Engineering/Design Completion at the Start of Construction	0.031
	Actual Percentage of Engineering/Design Completion at the Start of Construction	0.0789
Fiscal Planning	Number of Funding Phases	0.0737
	Clarity of Funding Process during Front End Planning	0.0592
Governance	Number of Financial Approval Authority Thresholds	0.028
Interfaces	Previous Collaboration Between Designer/Engineer and Contractor	0.017
	Number of Vendor Organizations	0.0095
	Number of Subcontractor Organizations	0.0679
	Number of Subcontractor Entities (Less than 5 vs. More than 5)	0.0337
	Number of Owner Organizations	0.0097
	Communication Effectiveness within Permitting Agencies Group	0.0864
	Communication Effectiveness within Owners Group	0.0368
	Communication Effectiveness within Agency's Group	0.0922
	Communication Effectiveness between Subcontractors and contractors Group	0.0116
Resources	Percentage of PM Staff Turnover	0.0624
	Field Craft Labor Quality Issues	0.0366
Scope Definition	Project Scope Similarity Level at Completion Compared to Authorization	0.0557
	Change Management Process Effectiveness in Controlling Cost and Schedule	0.0348
Stakeholder Management	Impact of Required Inspection by External Agencies	0.073
	Clarity of Owners Project Goals and Objectives	0.0261
Best Practices	Use of Materials Management Strategy	0.0176
	Use of Dispute Review Strategy	0.0268
	Risk Assessment Process Implementation	0.0556
	Planning for Start Up Implementation	0.0176
	Cumulative Influence of Best Practices Strategies	0.0704

Table 17 shows the leading indicators of schedule performance during the procurement phase. From the analyzed data, the "Interface" category with four potential leading indicators has the greatest impact on determining procurement schedule phase overrun. “Execution Targets” and “General Characteristics” are the next two major categories which impact schedule performance in this phase.

Table 17. Leading indicators for schedule overrun in procurement phase

Category	Significant Variables	P-Level
General Characteristics	Value of Engineering Driven Change Orders-Engineering/Design Phase	0.0908
	Project Engineering Schedule Performance	0.0723
Design & Technology	Difficulty in System Design and Integration	0.0421
Execution Targets	Cost Target at Authorization Compared to Industry Benchmarks	0.0251
	Actual Percentage of Engineering/Design Completion at the Start of Construction	0.0729
Interfaces	Previous Collaboration Between Designer/Engineer and Contractor	0.0692
	Number of Subcontractor Organizations	0.0818
	Number of Subcontractor Entities (Less than 5 vs. More than 5)	0.0522
	Number of Permitting Agency Organizations	0.0991
Location	Number of Execution Locations-Procurement Phase	0.0811
Resources	Field Craft Labor Quality Issues	0.0745
	Bulk Materials Quality Issues	0.0628
Scope Definition	Impact of Change Orders Timing	0.0161

Potential construction phase schedule performance leading indicators resulted from stepwise regression are shown in Table 18. As the results indicate, “General Characteristics” of the project have the highest number of potential variables in predicting construction phase schedule performance in a single category. Also, this part of the analysis concluded that cost and schedule performance of the engineering phase has impact on the schedule performance of the construction phase.

Table 18. Leading indicators for schedule overrun in construction phase

Category	Significant Variables	P-Level
General Characteristics	Project Baseline Schedule	0.0107
	Engineering/Design Phase Cost Overrun	0.0274
	Engineering/Design Phase Actual Schedule	0.0408
	Contribution of PMT Members in Procurement Phase- Average Number of Participants	0.0549
	Contract Containing Penalties for late completion	0.0555
Design & Technology	Company's Familiarity with Technologies Involved in Construction phase	0.0129
Execution Targets	Actual Percentage of Engineering/Design Completion at the Start of Construction	0.0604
Location	Project Population Density	0.0261
Resources	Delay in Delivery of Permanent Facility Equipment	0.0062
Scope Definition	Impact of Change Orders Timing	0.0144

6.3 Phase-Based Stepwise Regression for Cost Overrun

Table 19 shows the results of stepwise regression variable regression to identify potential engineering phase cost performance determinants. Based on this analysis, contract clauses related to late completion and liquidated damages could have a great impact on engineering phase cost performance.

Table 19. Leading indicators for cost overrun in engineering phase

Category	Significant Variables	P-Level
General Characteristics	Number of Owner Driven Change Orders- Engineering/Design Phase	0.0131
	Engineering/Design Phase Baseline Schedule	0.0196
	Engineering/Design Phase Actual Schedule	0.0605
	Contract Containing Penalties for late completion	0.0728
	Contract Containing Liquidated damages:	0.0212
	Project primary Nature	0.0869
Location	Project Documents Translated into a Different Language	0.0468
Resources	Reuse of Existing Installed Equipment	0.0756
Best Practices	Use of Alignment Strategy	0.0003

Potential procurement phase cost performance determinants are listed and classified in Table 20. According to the analysis, project management team experience during the procurement phase and engineering phase cost performance belonging to general characteristics are two major cost overrun determinants during the procurement phase.

Table 20. Leading indicators for cost overrun in procurement phase

Category	Significant Variables	P-Level
General Characteristics	Total Engineering Phase Change Orders	0.0994
	Project Management Team Experience -Procurement Phase	0.0914
	Project Engineering Cost Performance	0.0424
Design & Technology	Company's Familiarity with Technologies Involved in Construction phase	0.082
Governance	Number of Financial Approval Authority Thresholds	0.0743
	Number of Decision Making Entities Above PMT-Project Execution Plan	0.0934
Interfaces	Number of Permitting Agency Organizations	0.0853
	Number of Designer/Engineer Organizations	0.0449
Resources	Bulk Materials Quality Issues	0.0189
Stakeholder Management	Impact of Required Inspection by External Agencies	0.0832
Best Practices	Use of Quality Management Strategy	0.0356

Table 21 shows the results of the outcome of the stepwise regression variable reduction to identify cost performance during the construction phase. As the results show, project "General Characteristics" and "Resources" are the two major categories which have the highest number of construction phase cost performance determinants in a single category. This analysis concluded that procurement phase cost performance has a direct impact on the construction phase cost performance.

Table 21. Leading indicators for cost overrun in construction phase

Category	Significant Variables	P-Level
General Characteristics	Value of Owner Driven Change Orders-Engineering/Design Phase	0.0201
	Project Resource Leveling-Construction Phase	0.0037
	Procurement PMT Efficiency Level-Peak Number of Participants	0.0871
	Procurement Phase Cost Overrun	0.042
	Procurement Phase Cost	0.0436
	Procurement Phase Actual Schedule	0.0249
	Engineering/Design Phase Schedule Overrun	0.0766
	Engineering/Design Phase Cost Overrun	0.0987
	Engineering/Design Contract Type	0.0546
Design & Technology	Difficulty in System Design and Integration	0.0525
Governance	Number of Financial Approval Authority Thresholds	0.0869
Interfaces	Number of Owner Project Management Leadership Team Members	0.0586
	Number of Engineering/Design Entities (Single vs. Multiple)	0.0368
	Communication Effectiveness within Contractors Group	0.0846
Legal	Difficulty Level in Obtaining Design Approvals	0.0556
Location	Project Population Density	0.0775
Quality	Degree of Additional Quality Requirements - Construction Specifications	0.0284
Resources	Reuse of Existing Installed Equipment	0.0317
	Percentage of PM Staff Turnover	0.0339
	Percentage of Permanent Equipment Sourced Locally - Within Project Country	0.0646
	Percentage of Craft Labor Turnover	0.0900
	Delay in Delivery of Permanent Facility Equipment	0.0824
	Actual Percentage of Personnel Availability Compared to Project Plan	0.0879
Scope Definition	Design Percentage Completion Prior to Project Budget Authorization	0.0124
Stakeholder Management	Impact of Required Inspection by External Agencies	0.056
	Alignment Quality of Internal Stakeholders	0.0777
Best Practices	Front End Planning Process Implementation	0.0246

6.4 Summary

In this Chapter, the stepwise regression methodology was explained and used to further narrow down the number of phase-based cost and schedule overrun indicators. It should be noted that the output of the sequential variable reduction was used as input for the stepwise regression filtering analysis. In this part of the methodology, the cut-off p-value was raised from 0.05 to 0.1 to leave more number of variables for the next screening phase. Results of the stepwise regression used to identify cost and schedule performance indicators during each of the three phases of engineering/design, procurement and construction were presented by their categories. In next Chapter, the all-possible combinations regression method is explained and used to identify the final set of cost and schedule performance indicators during engineering/design, procurement and construction phases.

7. ALL-POSSIBLE COMBINATIONS REGRESSION

In regression analysis, analyzing the actual data to select the right set of predictor variables for constructing the final regression model is critical. For the purpose of variable selection, it is imperative that relying solely on theoretical principles and/or past experience may not yield the best possible outcome, and thus, these approaches should be only used to provide general guidelines.

Often, determining the best subset of independent (regressor) variables involves two opposing objectives; using the least number of variables to achieve the most accurate outcome. Including every independent variable that is somehow (even statistically insignificantly) related to the dependent variable can result in a fit (complete and realistic) model. At the same time, while introducing as many independent variables as possible to the model is intuitive in many cases, including irrelevant variables can be detrimental as it may decrease the precision of the estimated coefficients and ultimately, the predicted values. Also, the presence of extra variables may result in an increase in complexity of data collection and analysis, as well as model maintenance.

The goal of variable selection therefore becomes finding the right balance between fit (as many regressor variables as needed) and simplicity (as few regressor variables as possible). To this end, several strategies can be pursued. Generally, if there are no more than fifteen candidate variables, the all-possible regressions method (discussed in this Chapter) should be used since it will always give as good or better models than the stepwise regression (described in Chapter 6). In this study, considering the tradeoff between fit and simplicity, it was concluded that nine predictor variables would result in the best adjusted R-squared (and the least possible noise) in each model.

All-possible regression goes beyond stepwise regression as it tests all possible subsets of potential independent variables. If there are *k* potential independent variables (besides the constant), then there are 2^k distinct subsets of them to be tested (including the empty set which corresponds to the mean model). For example, for 15 candidate independent variables, the number of subsets to be tested is 2^{15}, which is 32,768, and if there are 30 candidate variables, the number is 2^{30}, which is more than 1 billion (1,073,741,824, to be precise). Clearly, analyzing these many subsets of variables is not computationally efficient and can easily turn into a resource intensive task.

When using an all-possible-regression procedure, a number of criteria can be used to rank the models. The two most commonly used criteria are adjusted R-squared and the Mallows' C_p statistic. The main difference between the former criterion and the latter is that the latter statistic includes a heavier penalty for increasing the number of independent variables. In addition, C_p is not measured on a scale of 0 to 1; rather, its values are typically positive and greater than 1, with lower values considered better. In this study, adjusted R-squared was used as a criteria to find the best predictive model for cost and schedule performance during the three phases of design, procurement and construction. The adjusted R-squared is a modified version of R-squared that has been adjusted for the number of predictors in the model.

7.1 Model Development for Cost and Schedule Performance

In this section, the all-possible regression models for project cost and schedule for each of the engineering/design, procurement and construction phases, as well as for the total of all three phases are developed and discussed. As shown in Table 22, the best all-possible regression project cost overrun model based on 44 observations has an adjusted R-squared of 0.72. The adjusted R-squared is a modified version of R-squared that has been adjusted for the number of predictors in the model. The adjusted R-squared increases only if the new term improves the model more than what would be expected by chance. It decreases when a predictor improves the model by less than expected by chance. The adjusted R-squared can be negative, although it is usually not, and it is always lower than the R-squared.

Table 22. Quality of regression model for total cost overrun

Regression Statistics-Total Cost Overrun	
Multiple R	0.88
R-Squared	0.78
Adjusted R-Squared	0.72
Standard Error	0.09
Observations	44

The final indicators of total project cost performance model are listed in Table 23. Based on the results, “alignment quality of internal stakeholders”, “planning for startup implementation, percentage of craft labor sourced locally”, “number of engineering/design entities”, “design percentage completion prior to project budget authorization”, “delay in delivery of permanent facility equipment”, “contract containing penalties for late completion”, “change management process followed by key project team members” and “engineering contract type” are the major and primary cost performance determinants.

As shown in Table 23, Number of the Engineering/Design Entities (TC4) is an indicator which is negatively related to the project cost overrun. To explain more, this means that if multiple engineering/design entities are involved in the project, there may be less project cost overrun due to the increased number of the diverse experts available to the project. As another example, if the project contract contains a higher level of penalties for late completion, the project will have less cost overrun. Moreover, if the organization responsible for delivery of the project has an enhanced process of incorporating a balanced change culture, the project will be completed with less cost overrun. A more detailed discussion on these variables are presented in Chapter 8.

Table 23. Total project cost overrun model

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.57	0.11	5.00	0.00	0.34	0.80	0.34	0.80
TC1	0.03	0.01	2.59	0.01	0.01	0.05	0.01	0.05
TC2	-0.07	0.01	-5.41	0.00	-0.09	-0.04	-0.09	-0.04
TC3	-0.02	0.01	-1.98	0.06	-0.04	0.00	-0.04	0.00
TC4	0.12	0.03	3.99	0.00	0.06	0.19	0.06	0.19
TC5	0.07	0.03	2.30	0.03	0.01	0.14	0.01	0.14
TC6	-0.04	0.01	-4.23	0.00	-0.05	-0.02	-0.05	-0.02
TC7	0.02	0.01	2.81	0.01	0.01	0.04	0.01	0.04
TC8	-0.06	0.03	-1.83	0.08	-0.12	0.01	-0.12	0.01
TC9	-0.05	0.01	-3.31	0.00	-0.08	-0.02	-0.08	-0.02

(TC1): Alignment Quality of Internal Stakeholders, (TC2): Planning for Start Up Implementation, (TC3): Percentage of Craft Labor Sourced Locally, (TC4): Number of Engineering/Design Entities (Single vs. Multiple), (TC5):Engineering/Design Contract Type, (TC6): Design Percentage Completion Prior to Project Budget Authorization, (TC7): Delay in Delivery of Permanent Facility Equipment, (TC8): Contract Containing Penalties for late completion, (TC9): Change Management Process Followed by Key Project Team Members

Table 24 illustrates the quality of all-possible regression model for total schedule overrun. This model which has been built based on 44 case studies, has an R-squared of 0.73, and an adjusted R-squared of 0.66.

Table 24. Quality of regression model for total schedule overrun

Regression Statistics-Total Schedule Overrun	
Multiple R	0.85
R-Squared	0.73
Adjusted R-Squared	0.66
Standard Error	0.16
Observations	44

As shown in Table 25, the total schedule performance predictive model consists of the following nine independent determinants: “project population density”, “project management team average size-engineering/design phase”, “previous collaboration between designer/engineer and contractor”, “number of subcontractor organizations”, “front end planning process implementation”, “delay in delivery of permanent facility equipment”, “contribution of PMT members in procurement phase-average number of participants”, “communication effectiveness within engineering/designers group”, and “change management process effectiveness in controlling cost and schedule”.

Table 25. Total project schedule overrun model

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.49	0.16	-3.07	0.00	-0.82	-0.17	-0.82	-0.17
TS1	0.03	0.01	2.08	0.04	0.00	0.06	0.00	0.06
TS2	0.00	0.00	1.40	0.17	0.00	0.01	0.00	0.01
TS3	-0.18	0.06	-3.04	0.00	-0.30	-0.06	-0.30	-0.06
TS4	0.01	0.00	3.75	0.00	0.01	0.02	0.01	0.02
TS5	0.07	0.02	3.63	0.00	0.03	0.11	0.03	0.11
TS6	0.04	0.02	2.77	0.01	0.01	0.08	0.01	0.08
TS7	0.09	0.02	4.33	0.00	0.05	0.14	0.05	0.14
TS8	-0.11	0.06	-1.90	0.07	-0.24	0.01	-0.24	0.01
TS9	0.02	0.02	1.39	0.17	-0.01	0.06	-0.01	0.06

(TS1): Project Population Density, (TS2): Project Management Team Average Size-Engineering/Design Phase, (TS3): Previous Collaboration Between Designer/Engineer and Contractor, (TS4): Number of Subcontractor Organizations, (TS5): Front End Planning Process Implementation, (TS6): Delay in Delivery of Permanent Facility Equipment, (TS7): Contribution of PMT Members in Procurement Phase-Average Number of Participants, (TS8): Communication Effectiveness within Engineering/Designers Group, (TS9): Change Management Process Effectiveness in Controlling Cost and Schedule

7.2 Phase-Based Model Development for Schedule Performance

In this section, three predictive models for schedule performance during engineering, procurement and construction phases are developed and discussed. The purpose of these models is not to predict the exact amount of schedule overrun; rather, they are intended to find major indicators of poor schedule performance.

7.2.1 Schedule Performance in Engineering/Design Phase

Table 26 shows the quality of all-possible regression model for schedule overrun in the engineering/design phase. As results illustrate, this predictive model has an R-squared of 0.79, and an adjusted R-squared of 0.74. This model represents the best schedule performance predictive model considering all possible regressions.

Table 26. Quality of regression model for schedule overrun in engineering phase

Regression Statistics-Schedule Overrun-Engineering Phase	
Multiple R	0.89
R-Squared	0.79
Adjusted R-Squared	0.74
Standard Error	0.22
Observations	44

As shown in Table 27, there are nine determinants in predicting engineering schedule performance during the early stages of a project. Results indicate that in order to improve engineering phase schedule performance, project managers should focus on the following features of the project: “risk assessment process implementation”, “Project Management Team (PMT) peak size-engineering/design phase”, “project execution driver”, “procurement PMT efficiency level-average number of participants”, “planned percentage of engineering/design completion at the start of construction”, “number of owner organizations”, “number of financial approval authority thresholds”, “change management process effectiveness in controlling cost and schedule”, and “actual percentage of engineering/design completion at the start of construction”.

As reported in Table 27, the implementation of a balanced change culture of recognition, planning and evaluation of project changes in an organization reduces the probability of extending the schedule during the design phase. Implementation of change culture makes the project participants ready to embrace owner’s change requests and manage to accomplish the owner’s desires effectively. Also, planned percentage of design completion at the start of construction (ES9) has an adverse relationship with the schedule performance during the design phase. This relationship concludes that if project design is more completed prior to the construction execution, engineering phase schedule performance may improve due to less design ambiguity and uncertainties. A more detailed discussion on these variables are presented in Chapter 8.

Table 27. Engineering phase schedule overrun model

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-1.06	0.25	-4.26	0.00	-1.56	-0.55	-1.56	-0.55
ES1	0.07	0.03	2.36	0.02	0.01	0.12	0.01	0.12
ES2	0.01	0.00	3.65	0.00	0.00	0.01	0.00	0.01
ES3	-0.14	0.05	-3.14	0.00	-0.24	-0.05	-0.24	-0.05
ES4	-0.26	0.07	-3.50	0.00	-0.41	-0.11	-0.41	-0.11
ES5	0.00	0.00	-2.21	0.03	-0.01	0.00	-0.01	0.00
ES6	0.09	0.03	3.02	0.00	0.03	0.16	0.03	0.16
ES7	0.11	0.03	3.97	0.00	0.05	0.16	0.05	0.16
ES8	0.12	0.02	5.59	0.00	0.07	0.16	0.07	0.16
ES9	0.01	0.00	4.60	0.00	0.01	0.02	0.01	0.02

(ES1): Risk Assessment Process Implementation, (ES2): Project Management Team Peak Size-Engineering/Design Phase, (ES3): Project Execution Driver, (ES4): Procurement PMT Efficiency Level-Average Number of Participants, (ES5): Planned Percentage of Engineering/Design Completion at the Start of Construction,(ES6): Number of Owner Organizations, (ES7): Number of Financial Approval Authority Thresholds, (ES8): Change Management Process Effectiveness in Controlling Cost and Schedule, (ES9): Actual Percentage of Engineering/Design Completion at the Start of Construction.

7.2.2 Schedule Performance in Procurement Phase

As it was discussed in the literature review section, there are few studies that focus on the project procurement phase cost and schedule performance. Table 28 shows the quality of the procurement phase schedule performance model. As results show, the ultimate predictive model has an R-squared of 0.76, and an adjusted R-Squared of 0.69.

Table 28. Quality of regression model for schedule overrun in procurement phase

Regression Statistics-Schedule Overrun-Procurement Phase	
Multiple R	0.87
R-Squared	0.76
Adjusted R-Squared	0.69
Standard Error	0.12
Observations	44

Based on the analysis, procurement phase schedule performance has nine independent indicators. Project engineering schedule actual performance is the first determinant of the procurement phase schedule performance. Schedule delay or any extension of engineering phase could have a great impact on procurement phase schedule performance. Previous collaboration between the designer/engineer and contractor is another determinant of procurement phase schedule performance. According to the analysis, previous collaboration between the engineer and the contractor can positively influence the process of ordering and delivering materials. The number of subcontractor organization entities is another procurement phase schedule overrun determinant. As shown in Table 29, an increase in the number of skilled and diverse subcontractors decreases the probability of potential procurement phase schedule delays. Furthermore, if there are any quality issues related to bulk construction materials, the procurement phase schedule will be affected negatively and the project will be probably delayed.

Number of execution locations during the procurement phase in another schedule performance determinant. If there are more than one execution locations in the procurement phase, the project will probably face schedule delays in this phase. “Difficulty in system design and integration”, “cost target at authorization compared to industry benchmarks”, and “actual percentage of engineering/design completion at the start of construction” are the other procurement phase schedule performance determinants. Table 29 illustrates all the details of the procurement phase schedule performance predictive model.

Table 29. Procurement phase schedule overrun model

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.07	0.10	0.68	0.50	-0.14	0.27	-0.14	0.27
PS1	-0.16	0.06	-2.78	0.01	-0.27	-0.04	-0.27	-0.04
PS2	-0.12	0.04	-2.71	0.01	-0.21	-0.03	-0.21	-0.03
PS3	0.01	0.00	2.65	0.01	0.00	0.02	0.00	0.02
PS4	-0.25	0.06	-3.90	0.00	-0.38	-0.12	-0.38	-0.12
PS5	0.01	0.00	2.96	0.01	0.00	0.01	0.00	0.01
PS6	0.03	0.01	2.58	0.01	0.01	0.06	0.01	0.06
PS7	0.03	0.02	2.19	0.04	0.00	0.06	0.00	0.06
PS8	0.07	0.02	4.39	0.00	0.04	0.11	0.04	0.11
PS9	0.00	0.00	-3.59	0.00	-0.01	0.00	-0.01	0.00

(PS1):Project Engineering Schedule Performance, (PS2):Previous Collaboration Between Designer/Engineer and Contractor, (PS3): Number of Subcontractor Organizations, (PS4): Number of Subcontractor Entities (Less than 5 vs. More than 5), (PS5): Number of Execution Locations-Procurement Phase, (PS6): Difficulty in System Design and Integration, (PS7): Cost Target at Authorization Compared to Industry Benchmarks, (PS8): Bulk Materials Quality Issues, (PS9): Actual Percentage of Engineering/Design Completion at the Start of Construction.

7.2.3 Schedule Performance in Construction Phase

Table 30 shows the quality of final predictive model for schedule performance during the construction phase. As results show, this model has an R-squared of 0.80, and an adjusted R-squared of 0.75.

Table 30. Quality of regression model for schedule overrun in construction phase

Regression Statistics-Schedule Overrun-Construction Phase	
Multiple R	0.89
R-Squared	0.80
Adjusted R-Squared	0.75
Standard Error	0.23
Observations	44

Construction phase schedule performance predictive model has nine independent determinants. As shown in Table 31, project population density is one of the project schedule performance indicators. Based on the results, if the project area is populated, there is a high probability that there will be a construction phase schedule overrun. For instance, issues such as congestion, city ordinances, and local government regulations may impose schedule constraints on certain types of field activities. Project baseline schedule is another schedule performance determinant during the construction phase. This study concluded that if the project has a more flexible baseline schedule, it will have less probability to face poor schedule performance. Timing of the change orders during the construction phase in also another schedule performance determinants. Late change orders during project execution cause the project to face extended delays and have a poor schedule performance. Engineering/design phase schedule performance is one more project schedule performance indicator. Based on the analysis, if a project faces schedule overrun during the engineering phase, it will encounter some delays during the construction phase as well. The same analysis revealed that assigning penalties in the contract for late completion reduces the probability of project delays during the construction phase. This issue could be explained by the fact that the contractor may assign more human and equipment resources to the project in order to avoid any construction phase delays.

Company's familiarity with technologies involved in the construction phase, actual percentage of engineering/design completion at the start of construction and construction phase budget are the last three indicators of construction phase schedule performance. As shown in Table 31, there would be less probability of poor schedule performance during the construction phase, (1) if the project crews are more familiar with the construction phase technologies, (2) if the project design is more complete at the start of the construction, and (3) if the project has a more flexible initial budget.

Table 31. Construction phase schedule overrun model

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.22	0.18	-1.22	0.23	-0.59	0.15	-0.59	0.15
CS1	0.07	0.02	3.09	0.00	0.02	0.11	0.02	0.11
CS2	-0.01	0.00	-3.03	0.00	-0.02	0.00	-0.02	0.00
CS3	0.06	0.02	2.74	0.01	0.02	0.10	0.02	0.10
CS4	0.39	0.16	2.47	0.02	0.07	0.71	0.07	0.71
CS5	0.05	0.01	8.31	0.00	0.04	0.06	0.04	0.06
CS6	-0.15	0.08	-1.87	0.07	-0.32	0.01	-0.32	0.01
CS7	-0.08	0.04	-2.23	0.03	-0.15	-0.01	-0.15	-0.01
CS8	0.00	0.00	-1.63	0.11	-0.01	0.00	-0.01	0.00
CS9	0.00	0.00	-2.50	0.02	0.00	0.00	0.00	0.00

(CS1): Project Population Density, (CS2): Project Baseline Schedule, (CS3): Impact of Change Orders Timing, (CS4): Engineering/Design Phase Cost Overrun, (CS5): Engineering/Design Phase Actual Schedule, (CS6): Contract Containing Penalties for late completion, (CS7): Company's Familiarity with Technologies Involved in Construction phase, (CS8): Actual Percentage of Engineering/Design Completion at the Start of Construction, (CS9): Construction Phase Budget.

7.3 Phase-Based Model Development for Cost Performance

7.3.1 Cost Performance in Engineering/Design Phase

Table 32 shows the quality of cost performance in engineering phase predictive model. As results show, this model has an adjusted R-squared of 0.49, and an R-squared of 0.35. The relatively low R-squared in this case is mainly the result of the data containing an inherently higher amount of unexplainable variability.

Table 32. Quality of regression model for cost overrun in engineering phase

Regression Statistics-Cost Overrun - Engineering Phase	
Multiple R	0.70
R-Squared	0.49
Adjusted R-Squared	0.35
Standard Error	0.22
Observations	44

Engineering phase cost overrun model has nine potential indicators during the early stages of the project. As these indicators are listed in Table 33, use of alignment strategy is a potential variable which improves cost performance during the engineering/design phase. The same analysis indicates that if more than one official language is used in the project (for instance, in case of an international project), the project will probably face cost overrun during the design phase.

Table 33. Engineering phase cost overrun model

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.54	0.12	4.55	0.00	0.30	0.78	0.30	0.78
EC1	-0.20	0.08	-2.38	0.02	-0.37	-0.03	-0.37	-0.03
EC2	0.02	0.01	1.40	0.17	-0.01	0.05	-0.01	0.05
EC3	-0.05	0.04	-1.02	0.31	-0.14	0.05	-0.14	0.05
EC4	-0.15	0.09	-1.66	0.11	-0.33	0.03	-0.33	0.03
EC5	0.00	0.00	-0.76	0.45	-0.01	0.00	-0.01	0.00
EC6	-0.01	0.01	-1.95	0.06	-0.03	0.00	-0.03	0.00
EC7	-0.13	0.09	-1.49	0.15	-0.30	0.05	-0.30	0.05
EC8	-0.07	0.09	-0.82	0.42	-0.25	0.11	-0.25	0.11
EC9	0.00	0.00	-0.36	0.03	0.00	0.00	0.00	0.00

(EC1): Use of Alignment Strategy, (EC2): Reuse of Existing Installed Equipment, (EC3): Project primary Nature, (EC4): Project Documents Translated into a Different Language, (EC5): Number of Owner Driven Change Orders-Engineering/Design Phase, (EC6): Engineering/Design Phase Baseline Schedule, (EC7): Contract Containing Penalties for late completion, (EC8): Contract Containing Liquidated damages, (EC9): Engineering/Design Phase Actual Schedule.

Increase in the number of owner driven change orders during the design phase is another indicator of poor cost performance. The reason behind this relationship is that unclear project scope usually leads to owner-driven change orders which in turn, require additional project funds to be sourced.

This analysis also indicates that if the project has a more flexible engineering/design phase baseline schedule, there will be less probability that it faces poor cost performance during this phase. Moreover, if the contract contains penalties for late completion as well as liquidated damages, the project will probably face lower cost overrun during the engineering phase. Finally, reuse of existing installed equipment and the project primary nature are the last two engineering phase cost performance indicators.

7.3.2 Cost Performance in Procurement Phase

Table 34 shows the quality of procurement phase cost performance predictive model. Based on the analysis, this model has an R-squared of 0.85, and an adjusted R-squared of 0.81.

Table 34. Quality of regression model for cost overrun in procurement phase

Regression Statistics-Cost Overrun - Procurement Phase	
Multiple R	0.92
R-Squared	0.85
Adjusted R-Squared	0.81
Standard Error	0.06
Observations	44

As shown in Table 35, there are nine procurement phase cost performance indicators. According to the analysis, use of quality management strategies improves cost performance of the project during the procurement phase. Value of engineering phase change orders is another independent variable which negatively affects project procurement phase cost performance. Project management team experience during the procurement phase is another cost performance indicator which reduces the potential cost overrun. Moreover, according to the analysis, poor engineering phase cost performance increases the probability of procurement phase cost overrun.

Number of permitting agency organizations, number of financial approval authority thresholds, number of designer/engineer organizations, company's familiarity with technologies and bulk materials quality issues are other procurement phase cost performance indicators. Based on the analysis, if more than one engineering/design entities are involved the project, there is a high probability that the project faces cost overrun during the procurement phase. Also, if there are any problems associated with the quality of bulk materials, the project will probably face procurement phase cost overrun.

Table 35. Procurement phase cost overrun model

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.03	0.04	-0.85	0.40	-0.12	0.05	-0.12	0.05
PC1	-0.07	0.02	-3.13	0.00	-0.11	-0.02	-0.11	-0.02
PC2	0.00	0.00	2.47	0.02	0.00	0.00	0.00	0.00
PC3	0.00	0.00	-2.92	0.01	-0.01	0.00	-0.01	0.00
PC4	-0.08	0.02	-3.57	0.00	-0.12	-0.03	-0.12	-0.03
PC5	-0.01	0.00	-9.14	0.00	-0.01	-0.01	-0.01	-0.01
PC6	-0.02	0.01	-2.32	0.03	-0.03	0.00	-0.03	0.00
PC7	0.05	0.01	4.41	0.00	0.03	0.07	0.03	0.07
PC8	0.05	0.01	4.99	0.00	0.03	0.07	0.03	0.07
PC9	0.02	0.01	2.34	0.03	0.00	0.03	0.00	0.03

(PC1): Use of Quality Management Strategy, (PC2): Total Engineering Phase Change Orders, (PC3): Project Management Team Experience -Procurement Phase, (PC4): Project Engineering Cost Performance, (PC5): Number of Permitting Agency Organizations, (PC6): Number of Financial Approval Authority Thresholds, (PC7): Number of Designer/Engineer Organizations, (PC8): Company's Familiarity with Technologies Involved in Construction phase, (PC9): Bulk Materials Quality Issues.

As Table 35 shows, implementing a quality management strategy improves project cost performance during the procurement phase. Also, results show that if the value of change orders during the engineering phase increases, there will be a negative impact on procurement phase cost performance. Moreover, if a project has poor performance during the engineering phase, there is a high chance of cost overrun in the procurement phase as well.

7.3.3 Cost Performance in Construction Phase

Table 36 shows the quality of construction phase cost performance predictive model. Based on the analysis, this model has an adjusted R-squared of 0.82, and an R-squared of 0.77 which implies that the construction phase cost performance predictive model fits the data well.

Table 36. Quality of regression model for cost overrun in construction phase

Regression Statistics-Cost Overrun - Construction Phase	
Multiple R	0.91
R-Squared	0.82
Adjusted R-Squared	0.77
Standard Error	0.19
Observations	44

Table 37 lists the independent project factors which could potentially predict the construction phase project performance. According to the analysis, percentage of project management staff turnover as well as percentage of craft labor turnover are two significant parameters which negatively affect construction phase cost performance. The reason behind this issue is that recruiting new project staff and labor is not only costly but also requires some time which may delay the project and cause more cost overrun later in the project. Percentage of permanent equipment sourced locally is another independent variable which has an impact on construction phase cost overrun. As results show, if the majority of the construction phase equipment is sourced locally, then the project would face less cost overrun due to the equipment transportation delays.

"Number of engineering/design phase entities" is another construction phase cost performance indicator. An increase in number of engineering organizations involved in the project could have both positive and negative impacts on the construction phase cost performance. Although engaging more engineering entities would provide more experienced human resources to the project, it may cause more disagreements and conflicts.

Table 37. Construction phase cost overrun model

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.72	0.12	-5.80	0.00	-0.97	-0.47	-0.97	-0.47
CC1	0.07	0.02	3.50	0.00	0.03	0.10	0.03	0.10
CC2	-0.06	0.02	-3.55	0.00	-0.10	-0.03	-0.10	-0.03
CC3	-0.16	0.04	-4.44	0.00	-0.24	-0.09	-0.24	-0.09
CC4	0.43	0.07	6.46	0.00	0.29	0.56	0.29	0.56
CC5	0.07	0.01	4.80	0.00	0.04	0.10	0.04	0.10
CC6	0.43	0.07	6.22	0.00	0.29	0.57	0.29	0.57
CC7	0.08	0.02	4.65	0.00	0.05	0.12	0.05	0.12
CC8	0.18	0.07	2.76	0.01	0.05	0.32	0.05	0.32
CC9	0.08	0.02	3.82	0.00	0.04	0.13	0.04	0.13

(CC1): Percentage of PM Staff Turnover, (CC2): Percentage of Permanent Equipment Sourced Locally - Within Project Country, (CC3): Percentage of Craft Labor Turnover, (CC4): Number of Engineering/Design Entities (Single vs. Multiple), (CC5): Impact of Required Inspection by External Agencies, (CC6): Engineering/Design Contract Type, (CC7): Delay in Delivery of Permanent Facility Equipment, (CC8): Communication Effectiveness within Contractors Group, (CC9): Alignment Quality of Internal Stakeholders.

Number of required inspections by external agencies could also increase construction phase cost overrun. If more inspection is required during the construction phase, there will be more shut down time which extends the project duration and increases project direct and indirect costs.

Design phase contract type, delay in delivery of permanent facility equipment, communication effectiveness within contractors group and alignment quality of internal stakeholders are the other construction phase cost performance determinants.

According to Table 37, if there is any delay in the delivery of permanent facility equipment, the project will face cost overrun during the construction phase. Therefore, project managers should pay careful attention to the schedule and actual delivery of permanent facility equipment.

7.4 Summary

In this Chapter, the all-possible combinations regression method was explained and used to identify the final set of cost and schedule performance indicators during engineering/design, procurement and construction phases. The most significant and influential variables were selected based on the highest adjusted R-squared among all the possible iterations. The list of significant indicators in predicting phase-based cost and schedule performance was presented and explained in some detail in this Chapter. In next Chapter, the application of the EBA method in analyzing the sensitivity of the phase-based cost and schedule overrun indicators is described, and EBA results of both Leamer's and Sala-i-Martin methods are presented.

8. EXTREME BOUNDS ANALYSIS (EBA)

The goal of EBA is to find out which independent variables (selected from a set of X) are robustly associated with the dependent variable y. A great deal of literature exists which contain detailed and rigorous description of EBA. Examples include Leamer (1985), Leamer and Leonard (1983), Sala-i-Martin (1997), McAleer, Pagan, and Volker (1985), Breusch (1990), Hendry and Krolzig (2004), and Angrist and Pischke (2010).

The process starts with running a large number of regression models, each containing y as the dependent variable, and including a set of standard explanatory variables F that are included in each regression model. In addition, each model includes a different subset D of the variables in X. The subset D whose regression coefficients are statistically significant in a large enough proportion of estimated models are denoted as robust, whereas those that do not are referred to as fragile. In order to determine if a variable $v \in X$ is robustly correlated with the dependent variable y, a set of regression models is estimated as follows,

$$y = \alpha_j + \beta_j v + \gamma_j F + \delta_j D_j + \varepsilon \tag{1}$$

In the EBA formulation, the regressions were estimated by Ordinary Least Squares (OLS). In recent research, however, other types of regression models have also been implemented. Examples include ordered probit models (Bjørnskov et al., 2008; Hafner-Burton 2005), and logistic models (Hegre and Sambanis 2006; Moser and Sturm 2011; Gassebner et al., 2013).

Figure 20 shows the difference between how fragile and robust variables impact the model output. As shown in this figure, the model output is more susceptible to slight changes in the input of a fragile variable. On the contrary, changes in the input of a robust variable do not significantly affect the model output.

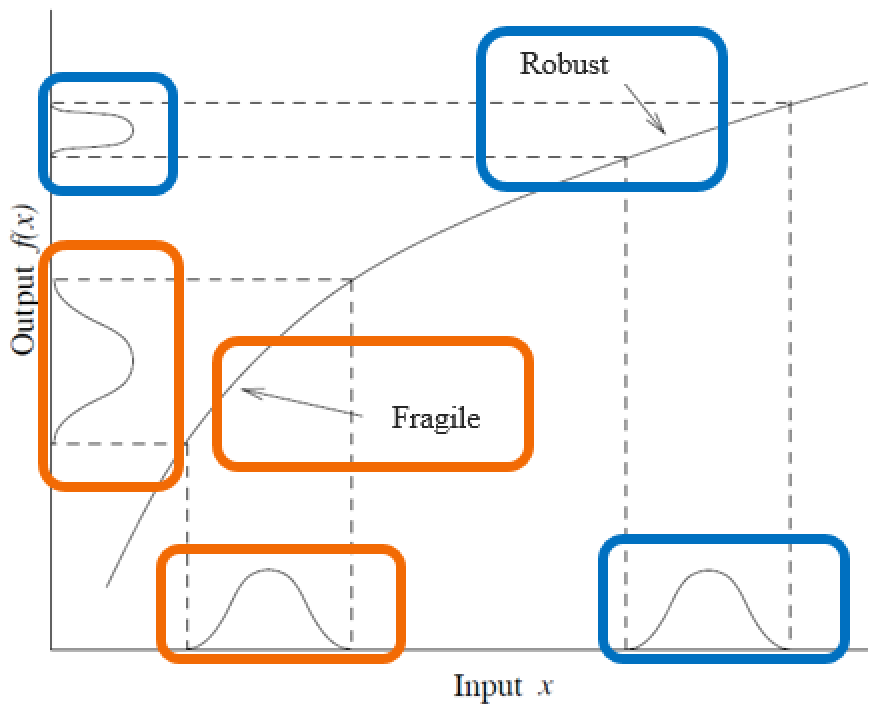

Figure 20. Comparison of fragile and robust variables.

Within the context of this study, identifying robust cost and schedule performance indicators during engineering/design, procurement and construction phases serves to guide project managers in allocating their limited human and machinery resources more effectively and efficiently during project execution. In particular, it is recommended that robust indicators receive higher priority when allocating scarce project resources since they are more likely to positively impact project cost and schedule performance.

8.1 Leamer's EBA

In order to decide whether a variable is robust or fragile, Leamer's EBA focuses only on the extreme bounds of the regression coefficients (Leamer 1985). In particular, for any variable *v*, the lower and upper extreme bounds are defined as the minimum and maximum values of $\hat{\beta}_j + \tau . \hat{\sigma}_j$ across the M estimated regression models, where τ is the critical value for the desired confidence level. For example, for 95 percent confidence level, a τ value of 1.96 is used. If the upper and lower extreme bounds have the same sign, variable *v* is declared robust, and if the opposite is true, it is referred to as fragile. The interval between the lower and upper extreme bounds represents the set of values that are not statistically significantly distinguishable from the coefficient estimate $\hat{\beta}_j$. In other words, a simple t-test would fail to reject the null hypothesis that the true parameter β_j equals any value between the extreme bounds. Intuitively, Leamer's version of EBA scans a large number of model specifications for the lowest and highest value that the β_j parameter could take at the desired confidence level. It then labels variables as robust or fragile based on whether these extreme bounds have the same or opposite signs, respectively. Perceivably, Leamer's EBA relies on a very demanding robustness criterion, since the results from a single regression model are enough to classify a variable as fragile. Figure 21 shows that the Leamer's EBA null hypothesis is set at zero. If the distribution curve of regression coefficients does not pass the null hypothesis value (i.e. zero), the variable is marked as robust. Also, following this figure, a variable is declared fragile even if the extreme bounds have the same sign in all but one of the estimated models. According to Sala-i-Martin (1997), "if the distribution of [regression coefficients] has some positive and some negative support, then one is bound to find one regression for which the estimated coefficient changes signs if enough regressions are run." Therefore, it is no surprise that studies that have used Leamer's EBA to test the robustness of variables have generally labeled most (if not all) as fragile (Levine and Renelt 1992; Levine and Zervos 1993; Sala-i-Martin 1997).

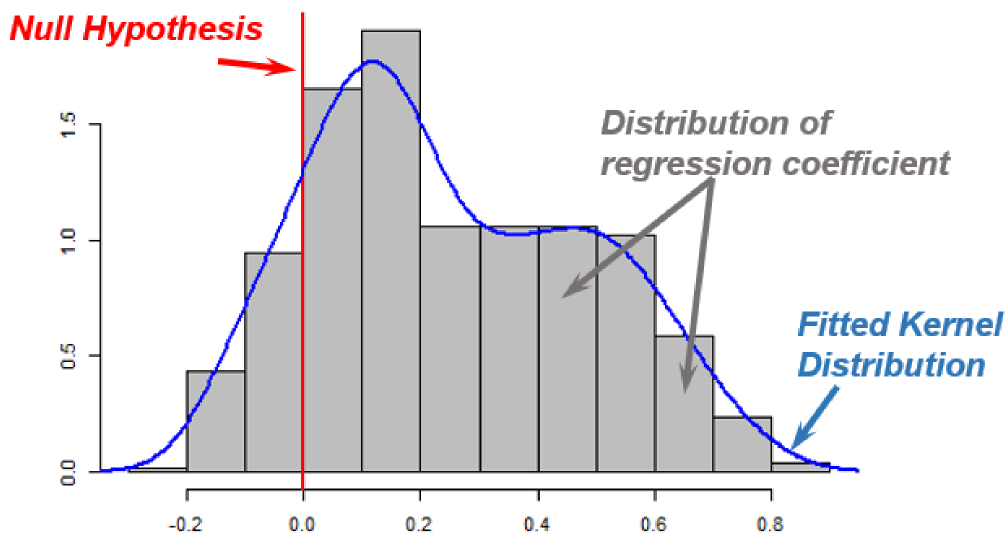

Figure 21. Illustration of EBA null hypothesis, distribution of regression coefficients, and fitted distribution.

8.2 Sala-i-Martin's EBA

To alleviate some of the drawbacks of the Leamer's EBA, Sala-i-Martin (1997) proposed an alternative EBA method that essentially focuses on the entire distribution of regression coefficients, instead of only its extreme bounds. Rather than applying a binary label of robust or fragile, this method assigns some level of confidence to the robustness of each of the variables. In particular, Sala-i-Martin (1997) considers the value of *CDF*(0), the fraction of the variable's cumulative distribution on each side of zero. According to the literature on Sala-i-Martin, "if 95 percent of the density function for the estimates of β_1 lies to the right of zero and only 52 percent of the density function for β_2 lies to the right of zero, one will probably think of variable 1 as being more likely to be correlated with [the dependent variable] than variable 2." In short, Sala-i-Martin's EBA considers a variable more robust if a greater proportion of its coefficient estimates lies on the same side of zero. It is understood that although the coefficients in each individual model have an asymptotic normal distribution, the coefficient estimates obtained from different regression models might be scattered less predictably and may not follow any particular distribution. For this reason, Sala-i-Martin (1997) presents two variants of his EBA: (1) a normal model, in which the estimated regression coefficients are assumed to follow a normal distribution across the estimated models, and a (2) generic model, which does not assume any particular distribution of regression coefficients.

8.3 Sensitivity Analysis of Project Total Cost and Schedule Performance

In this section, this study examines and investigates which of the regression determinants are robustly associated with the dependent variables. The results of EBA for each of the phase-based cost and schedule performance indicators are presented in Tables 38 through 45 that follow in this chapter. In each of the following EBA tables, the outcome of both Leamer's and Sala-i-Martin EBA methods are presented. In these tables, the two columns under Leamer's EBA test, the values of the upper and lower extreme bounds of the regression coefficients distributions are calculated. According to the Leamer's EBA method, if the sign of these two upper and lower extreme bound values change, the variable is fragile, and otherwise it is robust. This change of sign means that the relationship between the dependent and independent variables are not always in the same direction.

In the other part of the same tables, the results of the Sala-i-Martin are presented. Initially, Sala-i-Martin method evaluates if the distribution of the coefficients is normal or non-normal. This decision is made based on the graphical representation of the indicators' coefficient curves which are presented after these tables.

If the distribution is normal, then Salai-i-Martin considers how many percentage of each of the indicators are located on one side of the zero (either positive or negative) in different regression iterations. If more than 95 percent of the coefficient distribution of an independent variable is either positive or negative, that variable is considered robust, and otherwise it is considered fragile. The same 95 percent rule is applied if the distribution of the coefficients has a non-normal curve.

In this following sections, the robustness of the total and phase-based cost/schedule overrun determinants are analyzed and discussed. It should be noted that EBA results of both Leamer's and Sala-i-Martin methods are presented here. While EBA results from Leamer's method are primarily presented for reference, the final conclusion regarding the robustness or fragility of each indictor is solely made based on the Sala-i-

Martin EBA. Therefore, the decision that the distribution of coefficients of an indicator is normal or non-normal should be initially reached based on the graphical representations of Sala-i-Martin EBA for total and phase-based cost/schedule overrun (Figure 22 through Figure 29). The normality or non-normality of these indicators' coefficient curves helps to decide if each of the total and phase-based cost/schedule overrun indicators is either fragile or robust according to the Sala-i-Martin EBA method. It must be noted that the decision about the closeness of the indicators' distribution of regression coefficients to the Normal curve is primarily based on informed observation, which could be subjective depending upon an individual's own expertise in statistics. Once this determination is made, if the indicators' coefficients follow a normal distribution, values in columns 4 and 5 in Table 38 through Table 45 will be used to decide if an indicator is robust or fragile. Likewise, if the indicators' coefficients follow a non-normal distribution, values in columns 6 and 7 in Table 38 through Table 45 will be used to decide if an indicator is robust or fragile. If 95 percent or more of the coefficient distribution of an indicator is either positive or negative, that variable is considered robust, and otherwise it is considered fragile.

8.3.1 EBA Study of Project Total Cost Overrun

Figure 22 illustrates the normality or non-normality of coefficient distributions for total cost overrun indicators. As explained earlier, once a determination is made regarding the normality or non-normality of these indicators' coefficients, appropriate columns in Table 38 will be used to decide if an indicator is robust or fragile.

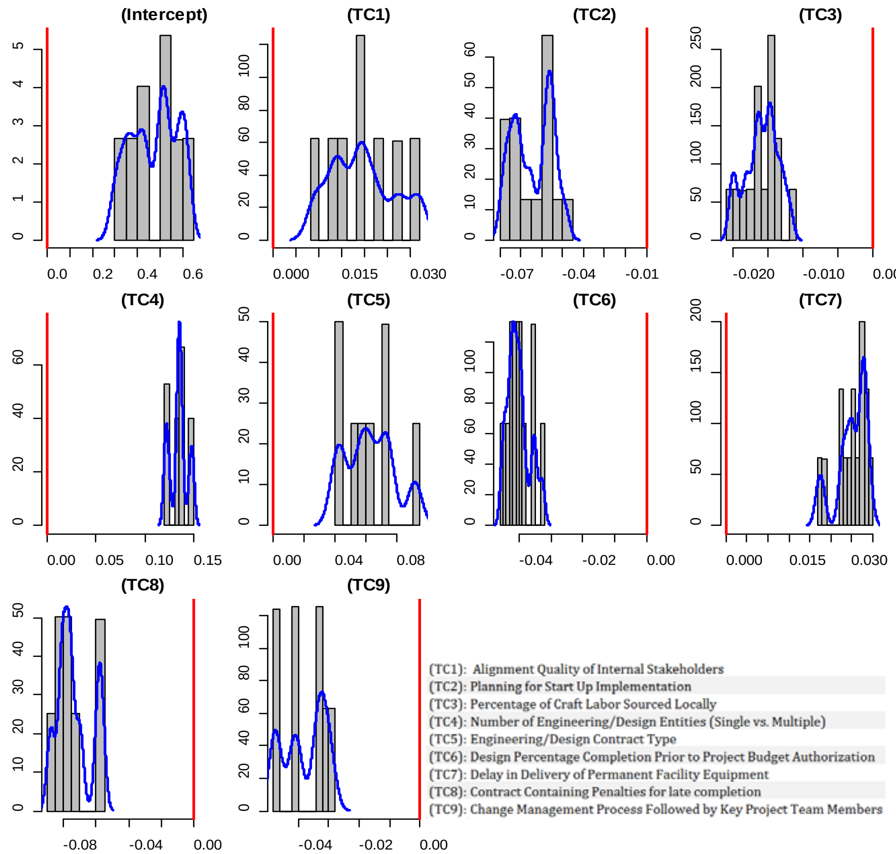

Figure 22. Graphical representation of Sala-i-Martin EBA for total cost overrun. The magnitudes of regression coefficients are on the horizontal axis. The vertical axis indicates the corresponding probability density.

As shown in Table 38, there are nine independent variables which predict the project cost overrun during early stages of the project. Table 38 illustrates the results of sensitivity analysis of the total cost overrun coefficients utilizing both Leamer and Sala-i-Martin methods. As it was explained earlier, Sala-i-Martin method is the enhanced version of Leamer method which considers the total distribution of the coefficients in the predictive models rather than just the initial and ending values of the independent variables. As it is presented in Table 38, Alignment Quality of Internal Stakeholders (TC1) is a robust variable and has an inverse relationship with total cost overrun. In other words, if internal project participants work within an acceptable tolerance to develop and meet uniform project goals and priorities, the project will have less cost overrun during the three phases of design, procurement and construction. TC1 is a robust variable as 100 percent of its coefficients' distribution has a negative relationship with the dependent variable.

Table 38. EBA study of the project total cost overrun predictive model

	Leamer EBA test		Sala-i-Martin EBA				
	Lower Extreme Bound	Upper Extreme Bound	Normal CDF(β<=0)	Normal CDF(β>0)	Non-Normal CDF(β<=0)	Non-Normal CDF(β>0)	Robustness
Intercept	0.10	0.86	0.00	100.00	0.03	99.98	Robust
TC1	-0.09	-0.01	100.00	0.00	99.99	0.01	Robust
TC2	-0.04	0.01	93.86	6.14	93.33	6.67	Fragile
TC3	0.05	0.22	0.01	99.99	0.01	99.99	Robust
TC4	-0.06	-0.02	100.00	0.00	100.00	0.00	Robust
TC5	0.01	0.05	0.03	99.97	0.07	99.93	Robust
TC6	-0.01	0.05	3.57	96.44	6.39	93.61	Fragile
TC7	-0.03	0.15	2.90	97.10	4.40	95.60	Robust
TC8	-0.15	0.01	98.70	1.30	98.25	1.75	Robust
TC9	-0.08	0.00	99.44	0.56	98.98	1.02	Robust

(TC1): Alignment Quality of Internal Stakeholders, (TC2): Planning for Start Up Implementation, (TC3): Percentage of Craft Labor Sourced Locally, (TC4): Number of Engineering/Design Entities (Single vs. Multiple), (TC5):Engineering/Design Contract Type, (TC6): Design Percentage Completion Prior to Project Budget Authorization, (TC7): Delay in Delivery of Permanent Facility Equipment, (TC8): Contract Containing Penalties for late completion, (TC9): Change Management Process Followed by Key Project Team Members

As shown in Table 38, Number of the Engineering/Design Entities (TC4) is another robust variable which is negatively related to the project cost overrun. To explain more, this means that if multiple engineering/design entities are involved in the project, there will be less project cost overrun due to the increased number of the diverse experts available to the project.

The other determinant of cost overrun predictive model, Percentage of Craft Labor Sourced Locally (TC3), is a fragile variable which is positively associated with the model outcome. To explain more, if the project manager hires majority of the craft labor locally, the project may endure more cost overrun. This issue could be explained by the increased cost of rework and/or lower labor productivity, if less experienced labors are available in the project area. However, since this is a fragile variable, an opposite impact may as well be the case since local labor requires less time and cost to commute, set up, and perform project tasks.

Design Percentage Completion Prior to Project Budget Authorization (TC6) is another fragile cost overrun determinant which can have a positive or negative relationship with the project cost overrun. As the bottom line, according to Leamer (1985), a fragile inference is not worth being taken seriously and its impact on the project cost overrun is not clear.

To explain the relationship of the remaining independent variables with project cost overrun, it is shown that the robust variable of the Delay in Delivery of Permanent Facility Equipment (TC7) has a positive relationship with the project cost overrun and the other two robust variables of TC8 (Contract Containing Penalties for late completion) and TC9 (Change Management Process Followed by Key Project Team Members) have adverse relationships with the project cost overrun. In other words, if there is a delay in the delivery of permanent facility equipment, the project will bear more cost overrun.

On the other hand, if the project contract contains a higher level of penalties for late completion, the project will have less cost overrun. Moreover, if the organization responsible for delivery of the project has an enhanced process of incorporating a balanced change culture, the project will be completed with less cost overrun.

8.3.2 EBA Study of Project Total Schedule Overrun

Figure 23 illustrates the normality or non-normality of coefficient distributions for total schedule overrun indicators. As explained earlier, once a determination is made regarding the normality or non-normality of these indicators' coefficients, appropriate columns in Table 39 will be used to decide if an indicator is robust or fragile.

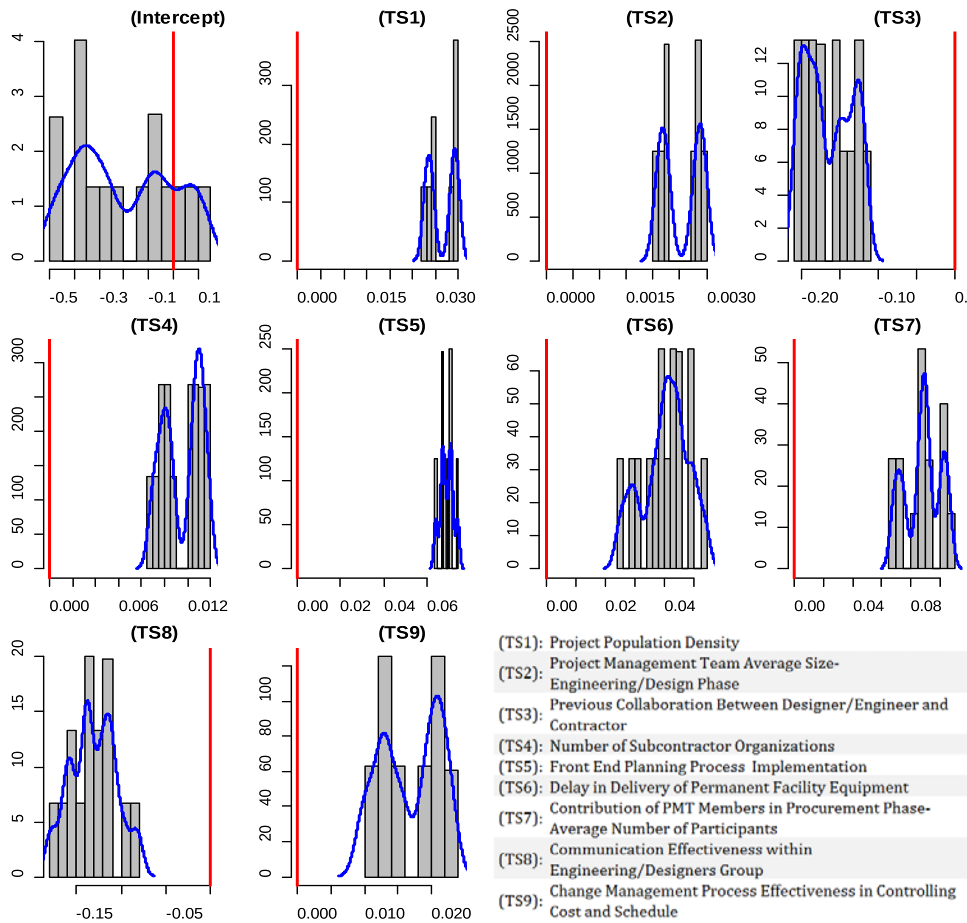

Figure 23. Graphical representation of Sala-i-Martin EBA for total schedule overrun. The magnitudes of regression coefficients are on the horizontal axis. The vertical axis indicates the corresponding probability density.

Table 39 shows the sensitivity analysis of the schedule overrun predictive model determinants. As it was explained earlier, the robust variables in the model are the ones to be focused on, as they are the major determinants of the outcome. Based on the schedule overrun EBA, it is revealed that seven out of nine independent variables of the schedule overrun model are robust, and only two TS7 (average number of PMT members in procurement phase) and TS9 (change management process effective in controlling cost and schedule) are fragile.

Table 39. EBA study of project total schedule overrun model

	Leamer EBA test		Sala-i-Martin EBA				
	Lower Extreme Bound	Upper Extreme Bound	Normal CDF(β<=0)	Normal CDF(β>0)	Non-Normal CDF(β<=0)	Non-Normal CDF(β>0)	Robustness
Intercept	-0.81	0.35	92.01	7.99	76.68	23.32	Fragile
TS1	-0.02	0.32	0.39	99.61	1.06	98.94	Robust
TS2	-0.02	0.00	99.89	0.11	99.63	0.37	Robust
TS3	-0.08	0.01	99.08	0.92	98.14	1.86	Robust
TS4	-0.15	0.02	99.99	0.01	99.95	0.05	Robust
TS5	-0.29	0.05	98.00	2.00	96.89	3.11	Robust
TS6	0.00	0.07	1.95	98.05	1.96	98.04	Robust
TS7	-0.01	0.00	92.41	7.60	92.24	7.76	Fragile
TS8	-0.11	-0.03	99.99	0.01	99.99	0.01	Robust
TS9	-0.06	0.03	82.32	17.68	81.86	18.15	Fragile

(TS1): Project Population Density, (TS2): Project Management Team Average Size-Engineering/Design Phase, (TS3): Previous Collaboration Between Designer/Engineer and Contractor, (TS4): Number of Subcontractor Organizations, (TS5): Front End Planning Process Implementation, (TS6): Delay in Delivery of Permanent Facility Equipment, (TS7): Contribution of PMT Members in Procurement Phase-Average Number of Participants, (TS8): Communication Effectiveness within Engineering/Designers Group, (TS9): Change Management Process Effectiveness in Controlling Cost and Schedule

As illustrated in Table 39, if the project location is populated (urban vs. rural) (TS1), there is a high chance that the project will be delayed. The same analysis shows that if the average size of the engineering/design phase project management team is larger (TS2), the project design will be completed faster and there is less probability that the project will be delayed. Moreover, if there was a previous collaboration between the engineering and contractor entities (TS3), the project will probably not face any delay due to conflicts between involving stakeholders. The same study shows that if the number of subcontractors involved in the project increases (TS4), the project will be completed faster with higher quality since greater number of experts and specialized workforce are involved in the project.

The same schedule overrun model sensitivity study indicates that implementation of the front end planning (TS5) results in a decrease in schedule overrun. Front end planning is the process of developing sufficient strategic information with which owners can address risk and decide to commit resources to maximize the chance of project success. Delay in delivery of permanent facility equipment (TS6) is another robust variable in predicting the behavior of project schedule performance. It is concluded that if there is a delay in delivery of permanent facility equipment, the project management team may need to revise the tasks' logistic which causes project schedule overrun.

The last robust project schedule performance indicator is the effectiveness level of communication within the engineering/design group (TS8). This study shows that if the project engineers communicate ineffectively, the project schedule will probably suffer and face unexpected delays.

Although the two fragile independent variables have less predictability capabilities in forecasting the project schedule overrun, they should be considered during the early phases of the project as well. This study highlights that if the change management process (incorporating a balanced change culture in an organization) (TS9) is implemented well and project management team commits more time and resources to the procurement phase, the project may have a streamlined workflow and thus, a more enhanced schedule performance.

8.4 Phase-Based Sensitivity Analysis of Project Schedule Performance

In this section, the robustness of project schedule overrun indicators in each of three engineering, procurement and construction phases is studied.

8.4.1 EBA Study of Project Schedule Overrun in Engineering/Design Phase

Figure 24 illustrates the normality or non-normality of coefficient distributions for engineering schedule overrun indicators. As explained earlier, once a determination is made regarding the normality or non-normality of these indicators' coefficients, appropriate columns in Table 40 will be used to decide if an indicator is robust or fragile.

As shown in Table 40, there are six robust and three fragile variables which determine the quality of schedule performance during the engineering phase. According to EBA results, if the average number of PMT participants during the engineering phase (ES2) increases, the project will face less schedule overrun during the design phase due to the availability of diverse skilled experts. Furthermore, this study reveals that if more owner entities are partnered up for a project, the engineering phase schedule will benefit due to the availability of more resources and collaboration of experienced practitioners.

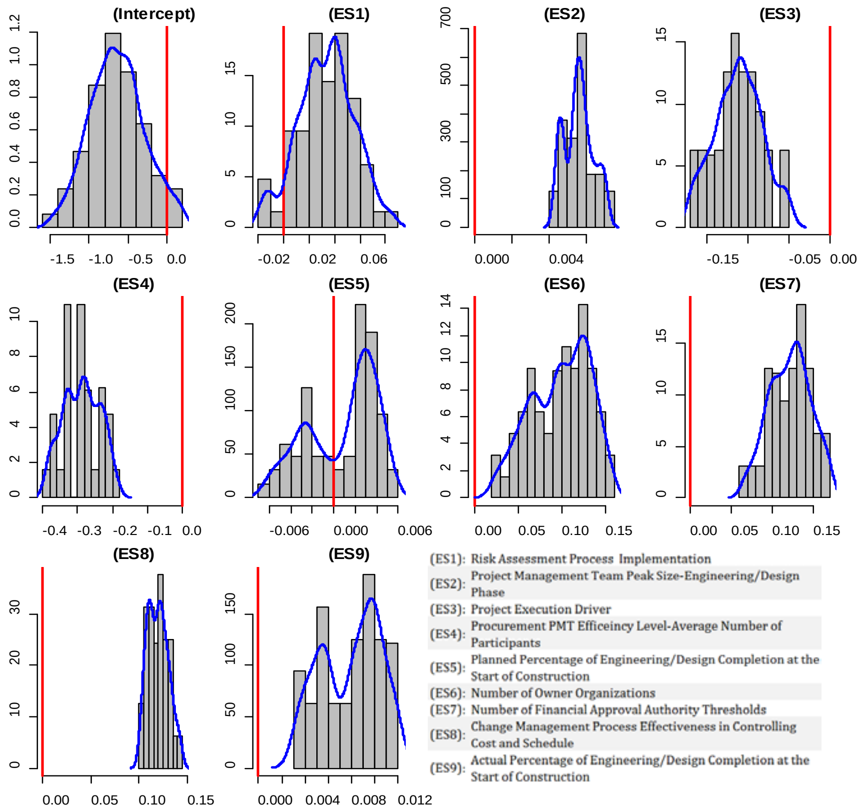

Figure 24. Graphical representation of Sala-i-Martin EBA for engineering schedule overrun. The magnitudes of regression coefficients are on the horizontal axis. The vertical axis indicates the corresponding probability density.

This study also indicates that if the number of financial approval authority thresholds in the project increases (ES7), the engineering phase schedule will suffer due to the uncertainties associated with the ultimate budget. When the design and construction budget is not fully approved and finalized, engineers will face difficulties in proceeding with the project design.

Table 40. EBA study of project engineering schedule overrun model

	Leamer EBA test		Sala-i-Martin EBA				
	Lower Extreme Bound	Upper Extreme Bound	Normal CDF(β<=0)	Normal CDF(β>0)	Non-Normal CDF(β<=0)	Non-Normal CDF(β>0)	Robustness
Intercept	-2.00	0.88	97.42	2.58	90.35	9.65	Fragile
ES1	-0.15	0.11	79.03	20.97	76.79	23.21	Fragile
ES2	-0.01	0.01	38.15	61.85	37.92	62.08	Fragile
ES3	-0.07	0.23	1.25	98.75	3.98	96.02	Robust
ES4	-0.01	0.00	99.49	0.51	99.25	0.75	Robust
ES5	-0.29	0.09	94.91	5.09	93.14	6.86	Fragile
ES6	-0.60	0.00	99.69	0.32	99.40	0.60	Robust
ES7	0.01	0.25	0.03	99.97	0.17	99.83	Robust
ES8	-0.21	0.05	100.00	0.00	100.00	0.00	Robust
ES9	-0.02	0.01	98.84	1.17	95.91	4.09	Robust

(ES1): Risk Assessment Process Implementation, (ES2): Project Management Team Peak Size-Engineering/Design Phase, (ES3): Project Execution Driver, (ES4): Engineering PMT Efficiency Level-Average Number of Participants, (ES5): Actual Percentage of Engineering/Design Completion at the Start of Construction,(ES6): Number of Owner Organizations, (ES7): Number of Financial Approval Authority Thresholds, (ES8): Change Management Process Effectiveness in Controlling Cost and Schedule, (ES9): Planned Percentage of Engineering/Design Completion at the Start of Construction.

As illustrated in Table 40, the change management process (ES8) and planned percentage of engineering/design completion at the start of construction (ES9) are the last two robust determinants of schedule performance during the engineering phase. According to results, the implementation of a balanced change culture of recognition, planning and evaluation of project changes in an organization reduces the probability of extending the schedule during the design phase. Implementation of change culture makes the project participants ready to embrace owner's change requests and manage to accomplish the owner's desires effectively. Also, planned percentage of design completion at the start of construction (ES9) has an adverse relationship with the schedule performance during the design phase. This relationship concludes that if project design is more completed prior to the construction execution, engineering phase schedule performance may improve due to less design ambiguity and uncertainties.

However, schedule performance during engineering/design phase also has three fragile indicators. Although these fragile variables will not have a considerable impact as the robust indicators, they could provide some information about the project schedule performance. This study found that implementation of the risk assessment process (ES1) could potentially improve the engineering phase schedule overrun due to the effective management of unexpected problems. Yet, planning for the risk assessment process could require more resource commitment and thus, negatively affect the project schedule during the engineering phase. Therefore, depending on the project nature, implementation of the risk assessment process should be considered consciously.

Peak number of project management team size during the engineering phase (ES2) is another fragile design schedule performance determinant which could have a positive or negative relationship. Increasing the size of the project management team could positively affect schedule performance since more human resources will be available to the project. At the same time, increasing the number of participants could cause more disagreements and conflicts between project members. As a result, the impact of peak number of PMT should be determined depending on other factors such as how large the number of participants or how complicated is the scope of the project.

8.4.2 EBA Study of Project Schedule Overrun in Procurement Phase

Figure 25 illustrates the normality or non-normality of coefficient distributions for procurement schedule overrun indicators. As explained earlier, once a determination is made regarding the normality or non-normality of these indicators’ coefficients, appropriate columns in Table 41 will be used to decide if an indicator is robust or fragile.

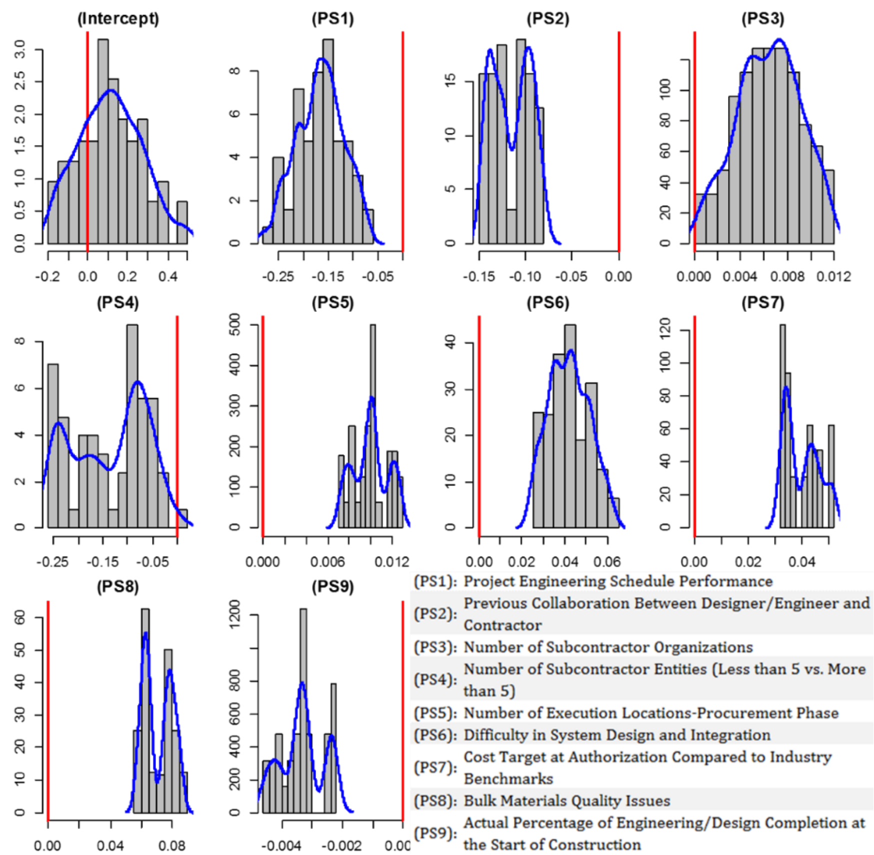

Figure 25. Graphical representation of Sala-i-Martin EBA for procurement schedule overrun. The magnitudes of regression coefficients are on the horizontal axis. The vertical axis indicates the corresponding probability density.

Table 41. EBA study of project procurement schedule overrun model

	Leamer EBA test		Sala-i-Martin EBA				
	Lower Extreme Bound	Upper Extreme Bound	Normal CDF(β<=0)	Normal CDF(β>0)	Non-Normal CDF(β<=0)	Non-Normal CDF(β>0)	Robustness
Intercept	-0.40	0.71	13.81	86.19	28.39	71.61	Fragile
PS1	-0.41	0.07	99.10	0.90	97.54	2.46	Robust
PS2	-0.01	0.02	8.16	91.84	11.88	88.12	Fragile
PS3	-0.40	0.18	95.75	4.25	89.36	10.64	Robust
PS4	-0.27	0.05	97.58	2.42	96.77	3.23	Robust
PS5	0.00	0.02	0.05	99.95	0.13	99.87	Robust
PS6	-0.01	0.10	0.44	99.56	0.99	99.01	Robust
PS7	-0.01	0.10	2.18	97.83	2.54	97.46	Robust
PS8	0.01	0.13	0.04	99.96	0.14	99.86	Robust
PS9	-0.01	0.00	99.87	0.13	99.39	0.61	Robust

(PS1): Project Engineering Schedule Performance, (PS2): Previous Collaboration Between Designer/Engineer and Contractor, (PS3): Number of Supplier Organizations, (PS4): Number of Subcontractor Entities (Less than 5 vs. More than 5), (PS5): Number of Execution Locations-Procurement Phase, (PS6): Difficulty in System Design and Integration, (PS7): Cost Target at Authorization Compared to Industry Benchmarks, (PS8): Bulk Materials Quality Issues, (PS9): Actual Percentage of Engineering/Design Completion at the Start of Construction.

Table 41 shows the results of the sensitivity analysis on schedule performance determinants during the procurement phase. As the results revealed, eight out of nine independent schedule performance variables during the procurement phase are robust and there is only one fragile indicator. Based on the analysis, project engineering schedule performance (PS1) will be an indicator of the project schedule overrun during the procurement phase. This problem happens when uncertainties in the design phase impose the proper planning in the procurement phase. The other robust procurement phase schedule overrun is the number of supplier organizations (PS3). This study indicated that if the number of suppliers to the project increases, there will be less schedule overrun. The reason for this relationship is that if more supplier organizations are involved, unavailability of a certain type of material will not affect the project as that material will be provided by other suppliers. The same study also concluded that if the number of subcontractors involved in the project (PS4) increases, there will be less procurement phase schedule overrun due to an increase in the number of skilled workers and the possibility of breaking the work down to smaller specialty tasks.

The outcome of the EBA in Table 41 shows that if there are multiple execution locations for a single project (PS5), there is a probability that the project schedule during the procurement phase will suffer. In such projects, program managers should have a detailed plan for distributing human and equipment resources across multiple locations.

Difficulty in system design and integration (PS6) is another robust procurement phase schedule performance indicator. System is the combination of several pieces of equipment to perform in a particular manner. If compared to other typical projects, there is a difficulty in system design and integration of the project, the procurement phase schedule could face an overrun.

Table 41 shows that if at the time of authorization, the project cost target is higher compared to the industry targets (PS7), the project has a high probability of facing schedule overrun in the procurement phase. This issue could be explained due to the complexity and difficulty of arranging the required resources for the larger scales projects.

Bulk material quality issues (PS8) is another robust procurement phase schedule overrun. Any material quality problem will slow down the execution process since those materials should be returned to the supplier and the new materials should be provided and delivered by the same supplier, or a new supplying organization should be found.

The last robust procurement phase schedule performance indicator is the percentage of design completion prior to the construction (PS9). As the analysis shows, if the design is more complete before construction starts, there will be less uncertainties associated with the project and thus, there is a low chance of schedule overrun in the procurement phase.

The only fragile procurement schedule performance determinant is the previous collaboration between the designer and the contractor (PS2). The relationship shows that previous collaboration between these two entities reduces the possibility of procurement phase schedule overrun. This event could be explained due to their familiarity with each other's processes as well as less potential for disagreement and conflicts.

8.4.3 EBA Study of Project Schedule Overrun in Construction Phase

Figure 26 illustrates the normality or non-normality of coefficient distributions for construction schedule overrun indicators. As explained earlier, once a determination is made regarding the normality or non-normality of these indicators' coefficients, appropriate columns in Table 42 will be used to decide if an indicator is robust or fragile.

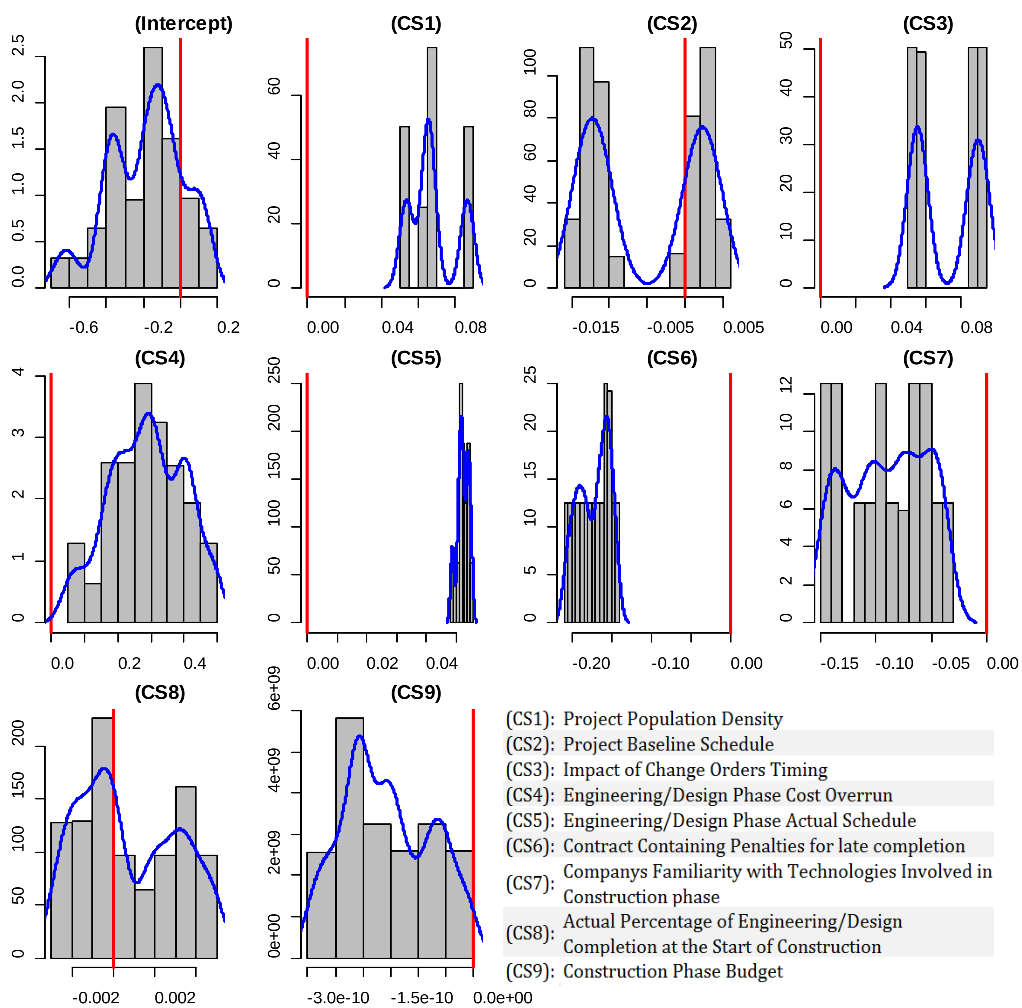

Figure 26. Graphical representation of Sala-i-Martin EBA for construction schedule overrun. The magnitudes of regression coefficients are on the horizontal axis. The vertical axis indicates the corresponding probability density.

As shown in Table 42, construction schedule performance has more fragile determinants than the other two phases. The reason behind the fragility of the indicators of this model is that there are more parameters involved in the construction phase which makes it harder to predict the impact of a single independent variable on the construction schedule. Based on the shown analysis, if the contract contains penalties for late completion (CS6), the construction schedule will face less overrun. However, not all contractors agree to pay high penalties due to unexpected delays. Therefore, high rate penalties for late completion could not always be included in the contractor's contract.

Table 42. EBA study of project construction schedule overrun model

	Leamer EBA test		Sala-i-Martin EBA				
	Lower Extreme Bound	Upper Extreme Bound	Normal CDF(β<=0)	Normal CDF(β>0)	Non-Normal CDF(β<=0)	Non-Normal CDF(β>0)	Robustness
Intercept	-1.26	0.75	77.45	22.55	72.18	27.82	Fragile
CS1	-0.02	0.01	90.71	9.29	66.71	33.29	Fragile
CS2	-0.51	1.01	10.18	89.83	11.99	88.01	Fragile
CS3	-0.01	0.01	39.08	60.92	47.16	52.84	Fragile
CS4	0.00	0.00	81.82	18.18	81.08	18.92	Fragile
CS5	-0.01	0.17	1.69	98.31	1.79	98.21	Robust
CS6	-0.17	0.01	99.05	0.95	99.16	0.84	Robust
CS7	-0.07	0.04	100.00	0.00	100.00	0.00	Robust
CS8	-0.52	0.13	91.29	8.71	92.22	7.78	Fragile
CS9	-0.26	0.04	95.80	4.20	94.46	5.54	Fragile

(CS1): Project Population Density, (CS2): Project Baseline Schedule, (CS3): Impact of Change Orders Timing, (CS4): Engineering/Design Phase Cost Overrun, (CS5): Engineering/Design Phase Actual Schedule, (CS6): Contract Containing Penalties for late completion, (CS7): Company's Familiarity with Technologies Involved in Construction phase, (CS8): Actual Percentage of Engineering/Design Completion at the Start of Construction, (CS9): Construction Phase Budget.

Another robust schedule performance indicator during the construction phase is the actual engineering/design schedule overrun of the same project (CS5). Based on the above sensitivity analysis, if the project has poor schedule performance during the design phase, there is a high chance that the project will face schedule overrun during the construction phase.

The last and the most robust construction phase schedule performance determinant is the company's familiarity with technologies involved in the construction phase (CS7). According to the EBA, if the crew is familiar with the technologies used in the construction phase, there will be less probability of project being delayed.

There are six fragile construction phase schedule performance determinants. Although these fragile indicators have less clear impact on the schedule performance during the construction phase, their effect should be studied. According to Table 42, if the project is executed in a populated area (CS1), there is a high chance that there will be schedule overrun during the construction phase. This issue could be explained due to the congested roadways which impose timely delivery of materials to the construction site. Another fragile construction phase schedule overrun determinant is the impact of change order timing (CS3). As the results show, if the change order is issued late in the construction phase, the construction phase will most probably be delayed due to the impact of the rework and other logistical issues.

Construction phase budget (CS9) is the other fragile construction phase schedule performance determinant. As this study concluded, if greater level of construction budget is available, there will be less schedule overrun since more human, material and equipment resources could be delivered to the project. This flexibility has a positive impact on the schedule performance behavior during the construction phase.

8.5 Phase-Based Sensitivity Analysis of Project Cost Performance

In this section, robustness of project cost performance determinants during the three phases of engineering/design, procurement and construction is studied.

8.5.1 EBA Study of Project Cost Overrun in Engineering/Design Phase

Figure 27 illustrates the normality or non-normality of coefficient distributions for engineering cost overrun indicators. As explained earlier, once a determination is made regarding the normality or non-normality of these indicators' coefficients, appropriate columns in Table 43 will be used to decide if an indicator is robust or fragile.

As shown in Table 43, six out of nine cost performance indicators of engineering phase are robust and the remaining three are fragile. As the analysis shows, if project documents are translated into a different language (EC4), it would be an indicator of cost overrun during the engineering phase. This issue could be justified taking into account that collaboration between engineers and designers who utilize different languages will slow down the process and may require additional steps before all drawings can be finalized. Moreover, international projects often require more resources to plan and execute. This slower process will ultimately negatively impact engineering phase cost performance due to the overhead costs.

The same analysis revealed that if the number of owner-driven change orders during the engineering/design phase increases (EC5), the engineering phase cost performance will suffer and there is a high chance of cost overrun in this phase. This poor cost performance could be explained due to the extra engineering hours required to satisfy the owner's change orders.

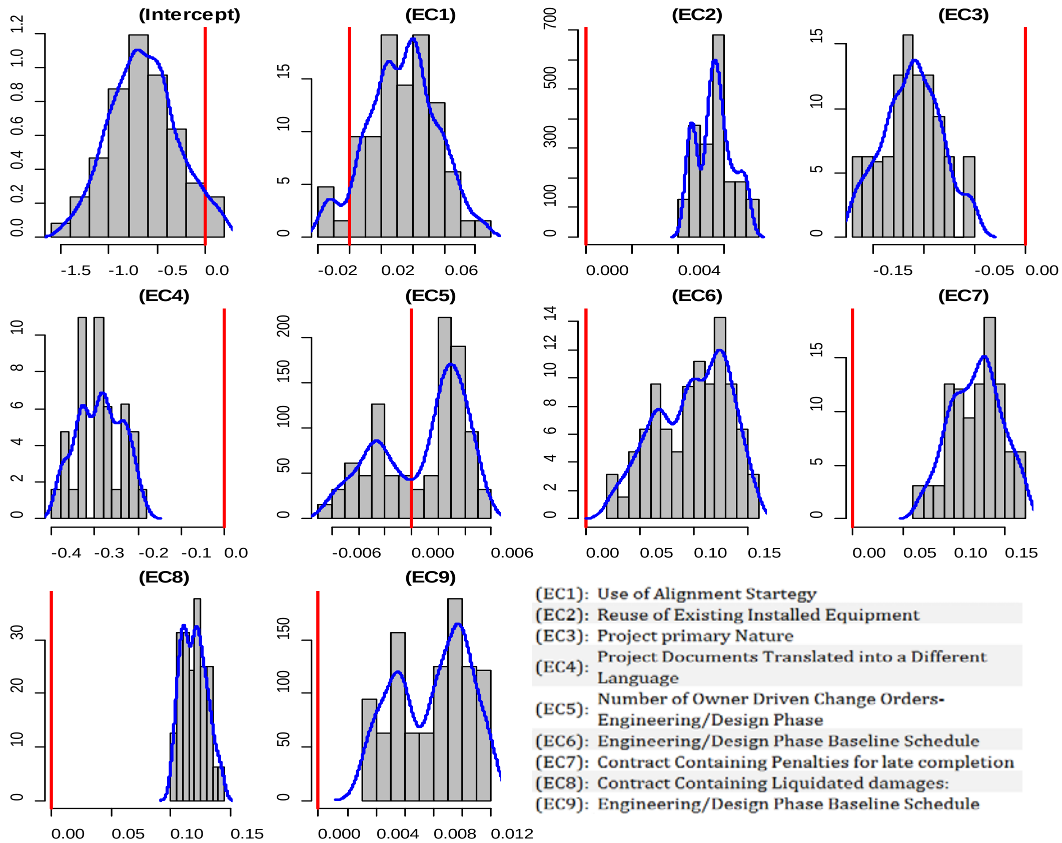

Figure 27. Graphical representation of Sala-i-Martin EBA for engineering cost overrun. The magnitudes of regression coefficients are on the horizontal axis. The vertical axis indicates the corresponding probability density.

Table 43. EBA study of project engineering cost overrun model

	Leamer EBA test		Sala-i-Martin EBA				
	Lower Extreme Bound	Upper Extreme Bound	Normal CDF(β<=0)	Normal CDF(β>0)	Non-Normal CDF(β<=0)	Non-Normal CDF(β>0)	Robustness
Intercept	-2.00	0.88	97.42	2.58	90.35	9.65	Robust
EC1	-0.15	0.11	79.03	20.97	76.79	23.21	Fragile
EC2	-0.01	0.01	38.15	61.85	37.92	62.08	Fragile
EC3	-0.07	0.23	1.25	98.75	3.98	96.02	Robust
EC4	0.00	0.01	0.51	99.49	0.75	99.25	Robust
EC5	-0.09	0.29	5.09	94.91	6.86	93.14	Fragile
EC6	-0.60	0.00	99.69	0.32	99.40	0.60	Robust
EC7	0.01	0.25	0.03	99.97	0.17	99.83	Robust
EC8	0.05	0.21	0.00	100.00	0.00	100.00	Robust
EC9	-0.02	0.01	98.84	1.17	95.91	4.09	Robust

(EC1): Use of Alignment Strategy, (EC2): Reuse of Existing Installed Equipment, (EC3): Project primary Nature, (EC4): Project Documents Translated into a Different Language, (EC5): Number of Owner Driven Change Orders-Engineering/Design Phase, (EC6): Engineering/Design Phase Baseline Schedule, (EC7): Contract Containing Penalties for late completion, (EC8): Contract Containing Liquidated damages, (EC9): Engineering/Design Phase Actual Schedule.

This study also concluded that if the contract contains penalties for late completion (EC7) as well as liquidated damages (EC8), the project engineering phase may face cost overruns due to the extra human resources required to complete the project on time. This issue could often happen when the project has a design-build project delivery and the engineering phase should be shortened to dedicate more time to the construction phase.

Table 43 also indicates that the engineering phase baseline schedule (EC6) is a robust indicator of design phase cost performance. These results show that if the project has a more flexible baseline schedule, there will be less probability that it faces engineering cost overrun.

It is also concluded that the use of alignment strategy (EC1) will reduce the probability of engineering phase cost overrun. Alignment is the condition where appropriate project participants are working within acceptable tolerances to develop and meet a uniformly defined and understood set of project priorities. The purpose of alignment is to focus the energy and talent of the team on a common goal by developing a common vision of project success and placing personal goals subservient to overall project success.

8.5.2 EBA Study of Project Cost Overrun in Procurement Phase

Figure 28 illustrates the normality or non-normality of coefficient distributions for procurement cost overrun indicators. As explained earlier, once a determination is made regarding the normality or non-normality of these indicators' coefficients, appropriate columns in Table 44 will be used to decide if an indicator is robust or fragile.

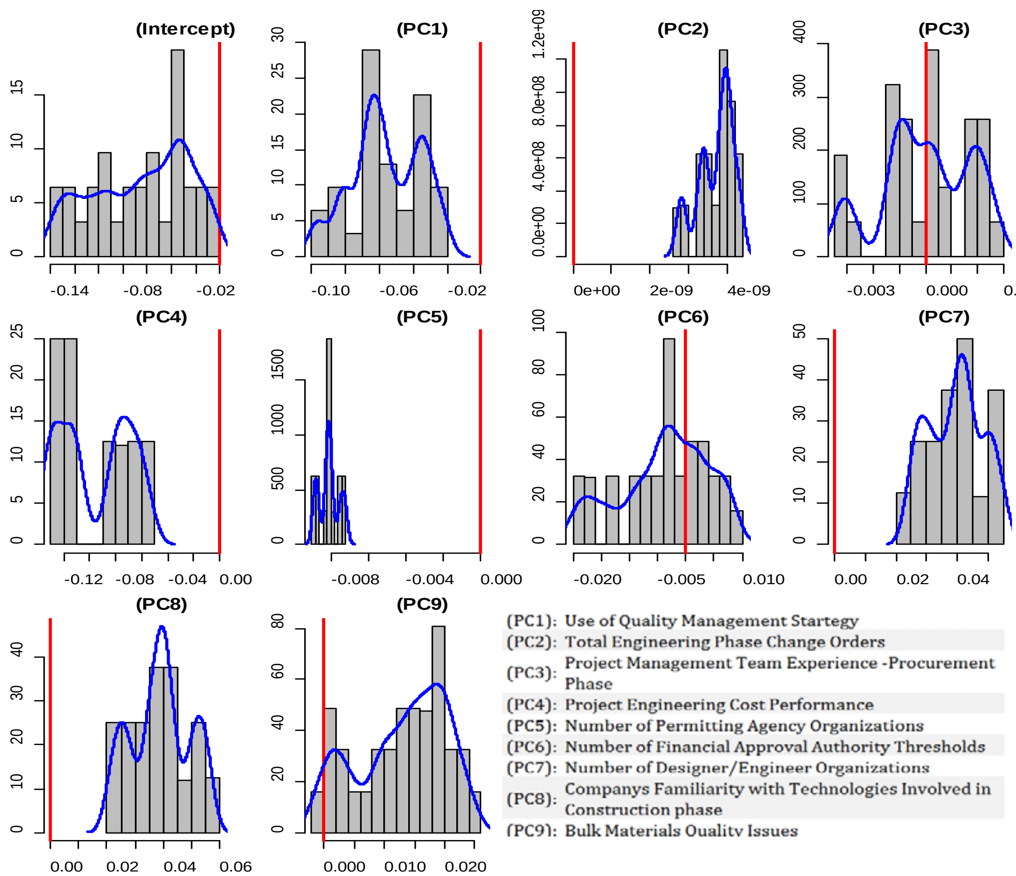

Figure 28. Graphical representation of Sala-i-Martin EBA for procurement cost overrun. The magnitudes of regression coefficients are on the horizontal axis. The vertical axis indicates the corresponding probability density.

Table 44 shows the results of sensitivity analysis of the procurement cost performance predictive model determinants. The analysis shows that if the number of permitting agencies increases (PC5), the procurement phase cost performance is likely to suffer. The same results also show that if there is a greater number of designer/engineer organizations involved in the project (PC7), the project will face less cost overrun during the procurement phase. This could be due to the availability of more diverse and skilled human resources. In this case, the designers would plan and select the project materials and logistics in a more optimized manner.

Company's familiarity with technologies involved in the construction phase (PC8) is another robust procurement phase cost performance indicator. According to this study, if the project utilizes technologies which have been successfully tested and used before, the procurement phase will face less cost overrun due to the presence of sufficient past information about the potential technologies and/or equipment to be purchased or used in the project.

Table 44. EBA study of project procurement cost overrun model

	Leamer EBA test		Sala-i-Martin EBA				
	Lower Extreme Bound	Upper Extreme Bound	Normal CDF(β<=0)	Normal CDF(β>0)	Non-Normal CDF(β<=0)	Non-Normal CDF(β>0)	Robustness
Intercept	-0.30	0.14	83.53	16.47	80.93	19.08	Fragile
PC1	-0.18	0.04	94.56	5.45	92.85	7.15	Fragile
PC2	-0.01	0.01	49.85	50.15	51.60	48.40	Fragile
PC3	-0.05	0.03	63.33	36.68	61.02	38.98	Fragile
PC4	-0.03	0.05	14.66	85.34	17.46	82.54	Fragile
PC5	0.00	0.00	2.57	97.43	2.61	97.39	Robust
PC6	-0.01	0.21	9.24	90.76	9.45	90.55	Fragile
PC7	-0.01	-0.01	100.00	0.00	100.00	0.00	Robust
PC8	-0.09	0.02	98.77	1.23	97.55	2.45	Robust
PC9	-0.02	0.08	0.78	99.22	3.24	96.76	Robust

(PC1): Use of Quality Management Strategy, (PC2): Total Engineering Phase Change Orders, (PC3): Project Management Team Experience -Procurement Phase, (PC4): Project Engineering Cost Performance, (PC5): Number of Permitting Agency Organizations, (PC6): Number of Financial Approval Authority Thresholds, (PC7): Number of Designer/Engineer Organizations, (PC8): Company's Familiarity with Technologies Involved in Construction phase, (PC9): Bulk Materials Quality Issues.

The same study shows that bulk materials quality issues (PC9) is another robust determinant of procurement phase cost performance. This sensitivity analysis explains that if there are quality issues with bulk materials, the project encounters procurement phase cost overrun due to the extra time spent on exchanging faulty fabricated materials.

This study concluded that there are also some fragile variables which could predict the procurement phase cost performance. As Table 44 shows, implementing a quality management strategy (PC1) improves project cost performance during the procurement phase. Quality management incorporates all activities conducted to improve the efficiency, contract compliance and cost effectiveness of design, engineering, procurement, QA/QC, construction, and startup elements of construction projects.

Engineering phase change orders (PC2) is the other determinant of procurement phase cost overrun. Results show that if the value of change orders during the engineering phase increases, there will be a negative impact on procurement phase cost performance. The reason behind this undesirable influence is that change orders issued by the owner may require some adjustments in the delivery of materials and equipment. Project engineering cost performance (PC4) is also an indicator of procurement phase cost overrun. Based on the EBA results, if a project has poor performance during the engineering phase, there is a high chance of cost overrun in the procurement phase as well.

PMT experience during the procurement phase (PC3) is the last fragile cost performance predictive model indicator which could impact cost overrun. PMT experience could help to better plan and manage procurement phase activities which in turn, reduces the possibility of cost overrun in this phase. However, experienced PMT members may be hesitant to try new and innovative methods of managing procurement activities in case any unexpected event happens during this phase. Therefore, depending on different project parameters, PMT experience could have favorable or unfavorable impact on procurement phase cost performance.

8.5.3 EBA Study of Project Cost Overrun in Construction Phase

Figure 29 illustrates the normality or non-normality of coefficient distributions for procurement cost overrun indicators. As explained earlier, once a determination is made regarding the normality or non-normality of these indicators' coefficients, appropriate columns in Table 45 will be used to decide if an indicator is robust or fragile.

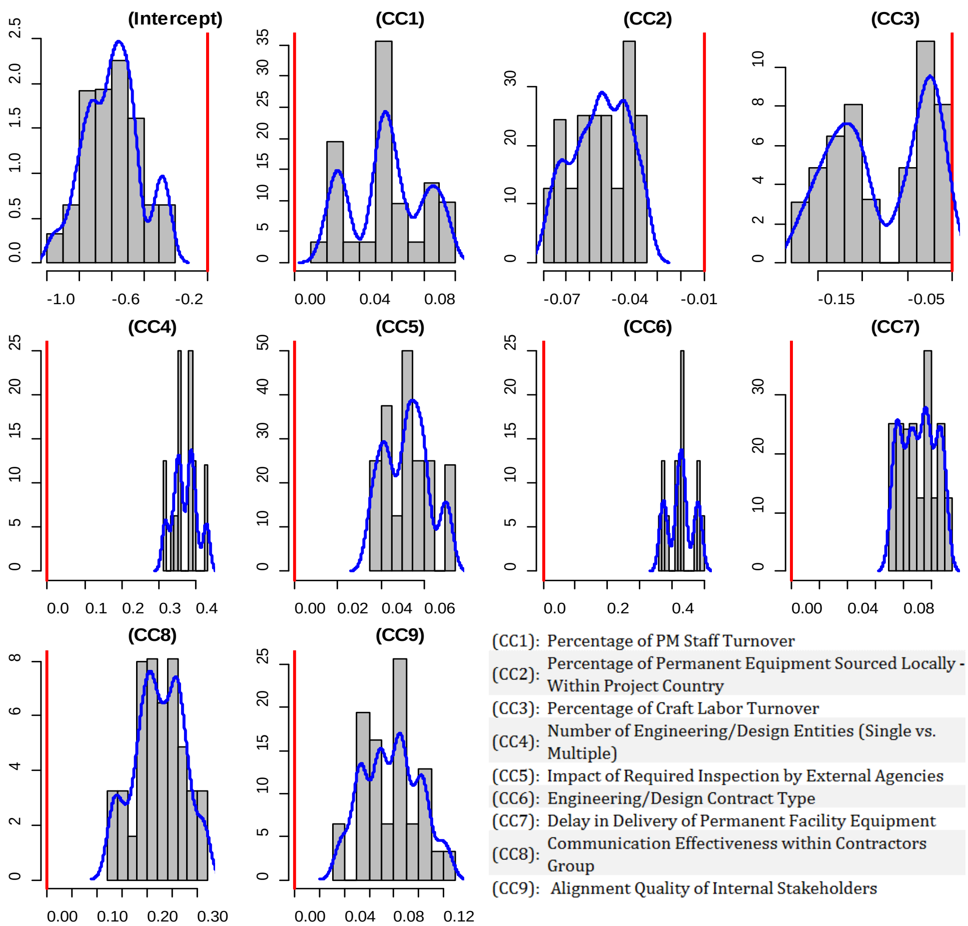

Figure 29. Graphical representation of Sala-i-Martin EBA for construction cost overrun. The magnitudes of regression coefficients are on the horizontal axis. The vertical axis indicates the corresponding probability density.

Table 45 shows the results of sensitivity analysis of the construction cost performance predictive model determinants. The analysis shows that seven out of nine model indicators are robust and only two of the determinants are fragile. EBA results indicate that percentage of project management staff turnover (CC1) is a robust determinant of construction phase cost overrun. To explain more, increase in the number of PM staff turnover causes poor construction phase cost performance. This loss could be due to extra funding required to hire qualified PM staff as well as the waste of time due to the learning curve required of the new project member.

The same analysis shows that both PM staff turnover (CC1) and craft labor turnover (CC3) have negative impacts on the construction cost performance. Based on the results, an increase in craft labor turnover increases construction phase cost overrun due to the cost of hiring, loss of productivity when new craft hired and also required training process.

Table 45. EBA study of project construction cost overrun model

	Leamer EBA test		Sala-i-Martin EBA				
	Lower Extreme Bound	Upper Extreme Bound	Normal CDF(β<=0)	Normal CDF(β>0)	Non-Normal CDF(β<=0)	Non-Normal CDF(β>0)	Robustness
Intercept	-1.19	0.19	99.96	0.04	98.57	1.43	Robust
CC1	-0.04	0.15	2.35	97.65	6.20	93.80	Robust
CC2	-0.26	0.12	92.63	7.37	84.07	15.93	Fragile
CC3	-0.08	0.52	1.72	98.28	2.66	97.34	Robust
CC4	-0.18	0.04	98.88	1.12	96.78	3.22	Robust
CC5	-0.12	0.03	95.13	4.87	93.12	6.88	Fragile
CC6	0.08	0.61	0.01	99.99	0.06	99.94	Robust
CC7	-0.02	0.11	1.12	98.88	2.58	97.42	Robust
CC8	-0.69	0.17	100.00	0.00	100.00	0.00	Robust
CC9	-0.16	-0.02	99.96	0.04	99.89	0.11	Robust

(CC1): Percentage of PM Staff Turnover, (CC2): Percentage of Permanent Equipment Sourced Locally - Within Project Country, (CC3): Percentage of Craft Labor Turnover, (CC4): Number of Engineering/Design Entities (Single vs. Multiple), (CC5): Impact of Required Inspection by External Agencies, (CC6): Engineering/Design Contract Type, (CC7): Delay in Delivery of Permanent Facility Equipment, (CC8): Communication Effectiveness within Contractors Group, (CC9): Alignment Quality of Internal Stakeholders.

Number of engineering/design entities (CC4) is another robust construction phase cost performance model determinant. As the results revealed, an increase in the number of engineering entities improves the construction phase cost performance. This relationship could be attributed to the better project design due to the availability of experienced, skilled and diverse human resources in the engineering phase. Moreover, delay in delivery of permanent facility equipment (CC7) is another robust indicator of project cost performance in construction phase. Results concluded that if delivery of facility equipment is delayed, the project would encounter cost overrun due to the need for rearrangement of the construction activities.

Communication effectiveness within contractors group (CC8) is another robust determinant of construction phase cost performance. As the sensitivity analysis suggests, improved communication within contractors group will reduce the likelihood of project cost overrun since there will be less conflicts and disagreements as well as more timely collaboration between the staff when accomplishing the work.

Alignment quality of the internal stakeholders (CC9) is the last robust variable which has an adverse relationship with construction phase cost performance. Internal stakeholders are people or organizations within the owner's company or joint venture, or within the design/contractor company that can exert influence on the outcomes of the project. Based on the results, if internal stakeholders align well in the project, there will be less possibility of construction phase cost overrun, due to reduced conflicts.

However, percentage of permanent equipment sourced locally (CC2) and impact of the required inspection by the external agencies (CC5) are two fragile determinants of construction phase cost performance. Based on the results, if most of the project permanent equipment are sourced within the same country, there will be less probability of construction phase cost overrun, due to less delay in equipment delivery and subsequent lower overhead costs. Furthermore, an increase in the number of required inspections by external agencies could results in poor construction phase cost performance. This relationship could be justified since increasing the number of inspections during the construction phase causes inefficiency due to the loss of time.

8.6 Summary

In this Chapter, the application of the EBA method in analyzing the sensitivity of the phase-based cost and schedule overrun indicators was described. In particular, EBA results of both Leamer's and Sala-i-Martin methods were presented. While EBA results from Leamer's method were primarily presented for reference, the final conclusion regarding the robustness or fragility of each indictor was solely made based on the Sala-i-Martin EBA. Findings were presented in both numerical and graphical forms. In practice, the purpose of identifying robust cost and schedule performance indicators during engineering/design, procurement and construction phases is to guide project managers in allocating their limited human and machinery resources more effectively and efficiently during project execution. In next Chapter, conclusions and potential directions for future work are presented and discussed.

9. CONCLUSIONS AND FUTURE WORK

The overarching goal of this study was to measure project success by identifying key construction cost and schedule performance determinants related to project general characteristics, specific features, and construction best practices for heavy industrial projects. This goal was successfully achieved through meeting three objectives as identified in Chapter 1. In particular, this study:

- Identified potential causes of delay and cost overrun in construction of heavy industrial projects during each of engineering/design, procurement and construction phases.
- Developed a model to predict cost and schedule overruns during each single phase of design/engineering, procurement and construction.
- Determined how robustly each of the engineering/design, procurement and construction cost and schedule indicators are associated with the project cost and schedule performance.

Based on the literature which was reviewed in Chapter 2, project cost and schedule performance were identified as two key defining components of project success. Most construction projects face delays and cost overruns during engineering/design, procurement and construction phases. However, the literature on determining phase-based cost and schedule performance indicators has to a large extent remained limited. Moreover, there are few studies that focused on the robustness and uncertainty of the most critical cost and schedule performance indicators.

Considering the existing gaps of knowledge and practice in this area, this dissertation was aimed at identifying cost and schedule performance indicators during all three design/engineering, procurement and construction phases. To this end, the CII-RT305 data set was used to carry out the designed research methodology which was explained in Chapter 3.

This study concluded that depending on the ultimate goal of the project in term of optimizing either of the cost or schedule or both, as well as the availability of resources during different project phases, a host of various best practices could be implemented. It was found that change management strategy is one of the most influential CII best practices to improve cost and schedule in parallel. According to CII, change management is the quality of incorporating a balanced change culture of recognition, planning and evaluation of project changes.

It was also found that the actual percentage of engineering/design completion prior to construction is a very significant schedule performance indicator in all three phases of engineering/design, procurement and construction. Based on the analysis, if the project execution initiates while the design of the project is not significantly completed, the project will most probably face schedule overrun.

It was also concluded that previous collaboration between the engineering entity and the contractor is another significant schedule performance indicator. The analysis determined that the existence of previous successful collaboration between these two parties would potentially reduce the probability of project schedule overrun during the procurement phase, ultimately leading to a reduced likelihood of total schedule overrun.

Moreover, the percentage of PM staff and craft labor turnover is another important factor that could cause significant losses and project delays. Furthermore, the number of engineering/design organizations involved is the third major predictor of cost and schedule performance. An increase in the number of design entities would offer more skilled and experienced human resources to the project which optimizes the project development process.

This research contributes to the field of construction engineering and management in two major ways. First, it identifies project factors/characteristics which drive poor project cost and schedule performance during the engineering/design, procurement and construction phases. Secondly, it determines the robustness of each of these cost and schedule performance indicators during the engineering/design, procurement and construction phases, which assists project managers to allocate their resources more effectively. Identifying and understanding phase-based cost and schedule indicators could potentially benefit high level managers of contracting companies in the decision making process regarding how to proceed with a specific project execution strategy. Same could also help the owners to have a more realistic view of the time and cost associated to the process of project development.

For future studies, the author recommends that the coupled impact of project cost and schedule performance be studied. For this purpose, it is suggested to define the success of a project by integrating the project total cost and schedule performances (as well as other potential key factors such as safety performance) and make a new project parameter. Categorizing the continuous data makes it possible to integrate the cost and schedule performance and develop a predictive logistic regression model to predict project success level during the front end planning phase. This model will help contractors to optimize both cost and schedule of the project at the same time.

Figure 30 explains how a project overall performance can be calculated. As shown in this figure, if a project has a good schedule and cost performance, it is considered in excellent performance group. Likewise, if a project has poor cost and schedule performance, it is presumed to be in poor performance category. However, moderate performance group represents projects which have either good cost and poor schedule performance, or poor cost and good schedule performance. Although the impact of poor/good cost might not be the same as poor/good schedule performance, this study assumes that they both cause project problems in the same undesirable direction and reduce probability of project success.

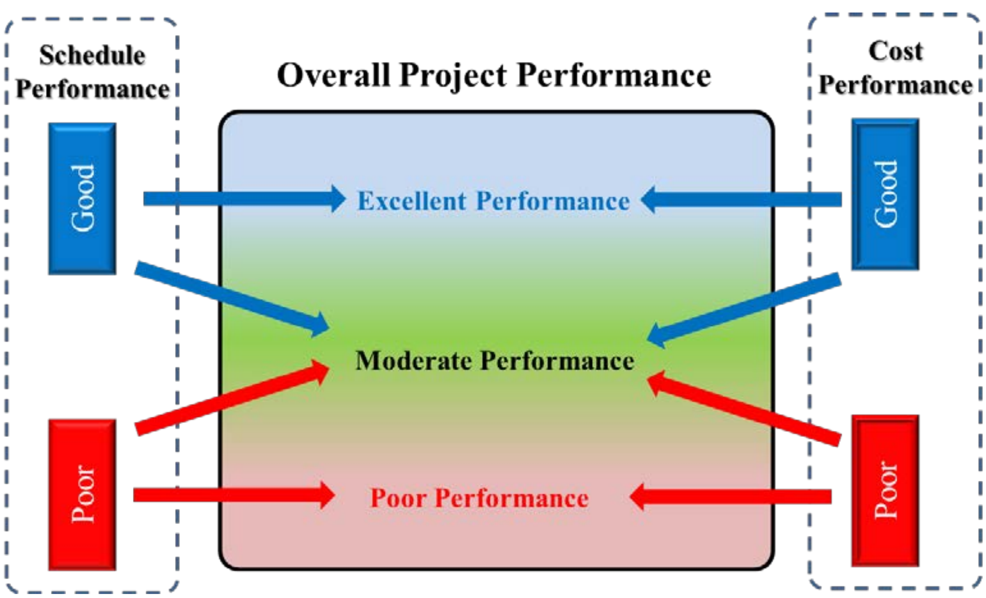

Figure 30. Overall project performance definition

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APPENDIX

CII Data Survey

The Knowledge Leader for Project Success

Owners • Contractors • Academics

RT 305 Measuring Project Complexity and Its Impact

Survey Questionnaire

Background

Complexity is a term often used in the construction industry to describe a project. However, there appears to be a limited understanding of project complexity, and no standard definition of what it means or how to measure it. Intuitively, the construction industry knows that project complexity has an impact on project delivery, project management practices, and project performance.

Research Team 305 is currently studying project complexity in an attempt to define, measure, and assess the impact of complexity on projects. Dr. Stuart Anderson, Texas A&M University, is the Principle Investigator for this study. Dr. Jennifer Shane, Iowa State University, is the Co-Principle Investigator. Their contact information is 979-845-2407, s-anderson5@tamu.edu and 515-294-1703, jsshane@iastate.edu, respectively.

RT 305 requests that the survey be completed for two projects by **October 14, 2013**.

This survey is voluntary and RT 305 will hold the data collected as strictly confidential in line with CII's confidentiality requirements as follows:

• Participating in this survey is voluntary.

• The data provided by participating companies in this survey will be confidential and used only for research purposes.

• The provided data will not be communicated in any form to any organization other than CII authorized academic researchers and designated CII staff members.

• To protect the confidentiality of companies submitting data, only aggregated data will be presented and published.

Survey Instruction

Every project is complex to some degree. Some projects are more complex than others.

RT 305 team wants to measure project complexity with respect to this continuum. Please select two projects that have been completed within the last three years or are almost complete such that the actual cost and actual schedule duration is known with almost certainty. One project should represent a project with low complexity and one project should represent a project with high complexity. Select the projects based on your perspective of complexity or the perspective of your organization.

1. Please identify whether the project covered in this survey is considered low or high in terms of project complexity (check one box only)?

☐ Low Level of Complexity

☐ High Level of Complexity

This survey has three parts: 1) General Project Description; 2) Project Complexity Metrics; and 3) Best Practice Implementation. Most survey questions are constructed so that they can be completed without considerable effort to find information relevant to the project. This assumes that the person completing the survey is very familiar with the subject project. Based on the pilot tests, the survey should take about one to two hours to complete per each survey depending on the availability of some project data. The quantitative data in the General Project Description of the survey might be best completed by the project controls lead or business manager.

Key Definitions

Stakeholders: "Person or organization (e.g. customer, sponsor, performing organization, or the public) that is actively involved in the project, or whose interests may be positively or negatively affected by the execution or completion of the project. A stakeholder may also exert influence over the project and its deliverable." (PMBOK, 4th edition, 2008)

Internal Stakeholders: Persons or Organizations within the Owner Company or Joint Venture Company or within the Designer/ Contractor Company that can exert influence on the outcomes of the project.

External Stakeholders: Partners, Governments, Public Agencies, Investors, NGOs that can exert influence on the outcomes of the project.

Interface: A common boundary or interaction between individuals or organizations.

Project Execution: Specific phases included under project execution include detailed engineering/design, procurement of permanent facility equipment and materials, construction, and start up.

Project Execution Plan: A formal document that defines in detail the proposed scope, schedule, budget, systems, methods and processes for executing the project. Some descriptors of a project execution plan include:

- Project schedule and budget
- Resources to be utilized
- Contracting strategy
- Drawing and modeling requirements
- Identification of design deliverables,
- Deliverable review and approval process
- Project controls and reporting plans
- Safety review requirements
- Process for reliability and maintenance inputs

Please proceed to the **Respondent Information** section to start the survey.

Respondent Information

2. Respondent Data

Name: ____

Company Name: ____

Email Address: ____

Years of Experience in Design and/or Construction: __________________

Describe Relationship to Project (e.g., project team member, sponsor, etc.)

For Owners:

3. What was your average Annual Capital Project Budget for the past three years?

☐ 0 to $100 million

☐ $100 million to $1.0 billion

☐ Greater than $1.0 billion

For Contractors

4. What was your average Annual Contract Revenue for the past three years?

☐ 0 to $100 million

☐ $100 million to $1.0 billion

☐ Greater than $1.0 billion

I. General Project Description

This section of the survey covers general characteristics about the project, factors that influence project execution (e.g., project delivery approach, project management team, etc.), and project performance information.

5. General Information

Project Name: ____

Project Owner(s):____

Primary Designer: ____

Primary Contractor: _______________________________________

Project Construction Location:

City: ___________, (State or Province):_____________, Country:_________

Lead design office location:

City: ____________, (State or Province):____________, Country:__________

When was construction completed? ___________ Year

6. What was your company's responsibilities for this project?

Non-owners, please check all that applied.

☐Front End Planning

☐Detail Design/Engineering

☐Procurement

☐Construction

☐Commissioning and Startup

COMPLETING THE REMAINING QUESTIONS:

PLEASE ANSWER ALL QUESTIONS BASED ON YOUR COMPANY'S RESPONSIBILITIES ON THIS PROJECT (IF QUESTION DOES NOT APPLY DO NOT ANSWER THE QUESTION OR CHECK THE "NOT APPLICABLE" (N/A) BOX)

7. Which of the following best describes the industry group for this project (Check one group only)?

☐ Heavy Industrial	☐ Light Industrial
- Chemical Manufacturing - Electrical (Generating) - Environmental - Metals Refining/Processing - Mining - Tailing - Natural Gas Processing - Oil/Gas Exploration/Production (well-site) - Oil Refining - Oil Sands Mining/Extraction - Oil Sands SAGD - Oil Sands Upgrading - Cogeneration - Pulp and Paper - Other Heavy Industrial	- Automotive Manufacturing - Consumer Products Manufacturing - Foods - Microelectronics Manufacturing - Office Products Manufacturing - Pharmaceutical Manufacturing - Pharmaceutical Labs - Pharmaceutical Warehouse - Clean Room (Hi-Tech) - Other Light Industrial
☐ Buildings	☐ Infrastructure
- Communications Center - Courthouse - Dormitory/Hotel/Housing/Residential - Embassy - Low rise Office ($\leq$3 floors) - High rise Office (>3 floors) - Hospital - Laboratory - Maintenance Facilities - Movie Theatre - Parking Garage - Physical Fitness Center - Prison - Restaurant/Nightclub - Retail Building - School - Warehouse - Other Buildings	- Airport - Central Utility Plant - Electrical Distribution - Flood Control - Highway (including heavy haul road) - Marine Facilities - Navigation - Process Control - Rail - Tunneling - Water/Wastewater - Telecom, Wide Area Network - Pipeline - Tank farms - Gas Distribution - Other Infrastructure

8. From the list below, please select the category that best describes the primary nature of this project.

☐ Grass Roots, Greenfield

☐ Brownfield (co-locate)

☐ Modernization, Renovation, Upgrade (changes to existing capacity)

☐ Addition, Expansion

☐ Environmental

☐ Other ____

Project Cost (Budget amounts include contingency and correspond to funding approved at time of authorization. This is the original baseline budget, and should not be updated to include any changes since change data are collected in a later section)

9. Please complete the following table:

Project Phases	**Baseline Budget**	**Actual Cost**	**Don't Know**
Total Project Cost	$_____	$_____	☐
Detailed Engineering/ design	$_____	$_____	☐
Procurement	$_____	$_____	☐
Construction	$_____	$_____	☐

10. Please complete the following table with respect to Change Orders.

	Total Number of Change Orders	**During Engineering/Design Phase**	**During Construction Phase**
Owner Driven	Number: _________; Value: $__________	Number: ______; Value: $___________	Number: _____; Value:$_______
Designer Driven	Number: _________; Value: $___________	Number: ______; Value: $___________	Number: _____; Value: $_______
Contractor Driven	Number: _________; Value: $_____________	Number: ______; Value: $___________	Number: _____; Value: $_______

11. Project Schedule (Schedule corresponds to approved schedule at time of authorization. This is the original baseline schedule, and should not be updated to include any changes since change data are collected in a later section)

Project Phases	**Baseline Budget**	**Actual Cost**	**Don't Know**
Total Project Cost	$_____ ______	$_____ ______	☐
Detailed Engineering/ design	$_____ ______	$_____ ______	☐
Procurement	$_____ ______	$_____ ______	☐
Construction	$_____ ______	$_____ ______	☐

12. Please select the primary factor influencing the execution of this project.

(Assume safety is a given on all projects.)

☐Cost

☐Schedule

☐Performance

13. Was this primary factor communicated to the project team?

☐Yes ☐No

14. What was the primary business driver for this project?

(Assume safety is a given on all projects**.**)

☐ Quality

☐ Capacity

☐ Risk

☐ Operability

☐ Environmental

☐ Social

☐ Others______________________

15. Were these drivers communicated to the project team?

☐Yes ☐No

16. Did your contract contain any of the following provisions?

A. Liquidated damages: ☐ Yes ☐No

B. Penalties for late completion: ☐ Yes ☐No

C. Bonuses for on time or early completion: ☐ Yes ☐No

17. Project Delivery Method

Please choose the project delivery method from those listed below that most closely characterizes the delivery method used for this project. If more than one delivery method was used, select the primary method.

Delivery Method		Description
☐	Design-Bid-Build	Serial sequence of design and construction phases; Owner contracts separately with designer and constructor.
☐	Design-Build (EPC)	Owner contracts with Design-Build (EPC) contractor.
☐	CM at Risk	Owner contracts with designers and construction manager (CM). CM holds the contracts.
☐	Multiple Primes	Owner contracts separately with designer and multiple prime constructors.
☐	Other	Please Describe:______________________

18. Contract Type

Please indicate below the contract types that were used on this project. If you had multiple contractors for a particular function, please answer the questions below in terms of what was most common.

Project Phase	Lump Sum	Cost Reimbursable (including unit price, Guaranteed Maximum Price)
Detailed Engineering/ design	☐	☐
Procurement	☐	☐
Construction	☐	☐

19. Project Scope

Please provide a brief description of the project scope (what is actually being designed / constructed), limit your response to 200 words.

____

____

____

____

____

____

____

20. Project Management Team

Project Management Team (PMT) Size and Participation

Please indicate the peak and average number of participants on the Project Management Team (PMT) during execution phase of the project. The execution phase of the project is defined to include detail engineering through mechanical completion. To account for individuals responsible for multiple projects, your response should reflect Full Time Equivalents (FTE's). FTE's represent the number of participants and the percent of time each is allocated to the project. For example, if one team member responsible for procurement works ½ time on the project, then the procurement contribution to the FTE measure is 0.5. Likewise, if two project controls specialists work on the team full time, they contribute 2.0 to the FTE.

For owners, the participant count should include owner or owner representative members of the PMT, but only those participants whose labor is accounted by the Owner as part of the cost of the project.

For contractor, participants do not include craft labors. Typical PMT participants are listed in the table below.

Typical PMT Participants	
Project Manager	Contracting
Engineering Manager / Project Eng.	Project Controls (Cost and Schedule)
Business Manager	QA / QC
Construction Manager	Safety
Operations Manager	Operations
Discipline Engineering Leads	Maintenance
Procurement Manager	Consultants

Project Phase	Estimated PMT Size		Estimated Years of Industry Experience
	Peak	Average	Average
Detailed Engineering/ Design	________ FTEs	________ FTEs	________ Years
Procurement	________ FTEs	________ FTEs	________ Years
Construction	________ FTEs	________ FTEs	________ Years

II. Project Complexity Metrics

The following section focuses on indicators of project complexity. Some questions are quantitative (i.e., a number) and some questions are qualitative (i.e., a categorical scale one to seven). Please answer the following questions.

21. What was the influence of this project on the organization's overall success (e.g., profitability, growth, future industry position, public visibility, and internal strategic alignment)?

Limited Contributor to Organization's Success		Moderate Contributor to Organization's Success			Substantial Contributor to Organization's Success	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

22. How many stakeholders had an active role (i.e., monthly input) in decision making on the project?

	Number of Decision Makers
Internal Stakeholders	Number:_____
Internal Stakeholders	Number:_____
External Stakeholders	Number:_____

23. How well aligned were these stakeholders?

	Extremely Aligned			Moderately Aligned			Not at all Aligned
	1	2	3	4	5	6	7
With Internal Stakeholders	☐	☐	☐	☐	☐	☐	☐
With External Stakeholders	☐	☐	☐	☐	☐	☐	☐

24. How clear were the owner's project goals and objectives at kick-off of project execution?

Extremely Clear			Somewhat Ambiguous			Completely Ambiguous
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

25. What was the impact of required approvals from internal stakeholders on the original project execution plan?

No Impact on Project Execution Plan		Moderate Impact on Project Execution Plan			Substantial Impact on the Project Execution Plan (required Planning)	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

26. What was the impact of required approvals from external stakeholders on the original project execution plan?

No Impact on Project Execution Plan		Moderate Impact on Project Execution Plan			Substantial Impact on the Project Execution Plan (required Planning)	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

27. What was the impact of required inspection by external (regulatory) agencies/entities on original project execution plan?

No Impact on Project Execution Plan		Moderate Impact on Project Execution Plan			Substantial Impact on the Project Execution Plan (required Planning)	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

28. How many executive oversight entities above the project management team had decision-making authority on your project execution plan?

(Please do not include project management team members shown in Table 1)

Number: __________

29. How many financial approval authority thresholds existed on your project?

(Example: the project manager can approve purchase orders up to $100K, the division director can approve purchase orders up to $1M, etc.).

Number: __________

30. What was the maximum number of authority levels above the Project Manager needed for change order approval?

Number: __________

31. How many times on this project did a change order need to go above the Project Manager for approval?

Number: __________

For Owner:

32. How many total sponsoring entities, or joint venture partners with an equity position, existed on this project?

Number: __________

For Contractors:

33. How many total joint-venture partners were there in this project?

Number: __________

34. Approximately how many regular status reports were completed in six months by the project team that are intended for executive management?

Number: __________

35. How many total permits were required?

Permits required by regulatory agencies to legally start site construction work (e.g. government environmental permits, Corps of Engineers permits)

Number: __________

36. What was the difficulty in obtaining permits?

Not at all difficult		Moderate Impact on Project Execution Plan			Extremely difficult	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

37. How many external (regulatory) agencies/entities were required to approve the design?

Number: __________

38. What was the difficulty in obtaining design approvals?

Not at all difficult		Moderate Impact on Project Execution Plan			Extremely difficult	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

39. Please indicate the impact of external agencies on the project execution plan.

Caused No Problems Meeting the Execution Plan		Caused Some problems Meeting the Execution Plan			Caused Substantial Problems Meeting the Execution Plan	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

40. What was the number of funding phases (gates) from concept to project completion?

Number: ____________

41. Did the project experience any delays or difficulties in securing project funding?

☐Yes ☐No ☐Don’t Know

42. Was the funding process well understood during the Front End Planning phase?

Extremely Clear			Somewhat Ambiguous			Completely Ambiguous
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

43. Did project economics (ability to meet desired rate of return or benefit to cost ratio greater than 1.0)

☐Yes ☐No

44. Please complete the following table regarding the number of organizations, effectiveness level of their communication, and number of project management leadership team members.

Leadership team member would be the same as those shown in Table 1.

	Number of Organizations	Number of Project Management Leadership Team members
Owner	Number:____	Number:_____
Prime Designers/Organizations	Number:_____	Number:____
Prime Contractors/Organizations	Number:_____	Number:_____
Subcontractors to Prime Contractors/Organizations	Number:_____	NA
Vendors to Prime Contractors or Subcontractors	Number:_____	NA
Permitting Agencies (for construction)	Number:_____	Number:_____

45. How effective was the communication within each participant group?

	Effectiveness of communication						
	Extremely effective			Moderately effective		Not at all effective	
	1	2	3	4	5	6	7
Owner	☐	☐	☐	☐	☐	☐	☐
Prime Designers/ Organizations	☐	☐	☐	☐	☐	☐	☐
Prime Contractors/ Organizations	☐	☐	☐	☐	☐	☐	☐
Subcontractors to Prime Contractors/ Organizations	☐	☐	☐	☐	☐	☐	☐
Vendors to Prime Contractors or Subcontractors	☐	☐	☐	☐	☐	☐	☐
Permitting Agencies	☐	☐	☐	☐	☐	☐	☐

46. Have the owner and the primary designer/engineer worked together before this project?

☐Yes ☐No ☐Don't Know

If yes, how many times have they worked together? ____________

47. Have the owner and the primary contractor worked together before this project?

☐Yes ☐No ☐Don't Know

If yes, how many times have they worked together? ____________

48. Have the primary designer/engineer and the primary contractor worked together before this project?

☐Yes ☐No ☐Don't Know

If yes, how many times have they worked together? ____________

49. Was the process for defining the project's scope understood during the selection of designers and contractors?

Extremely Clear			Somewhat Ambiguous			Completely Ambiguous
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

50. What percentage of design was completed prior to project budget authorization?

☐	☐	☐	☐	☐	☐	☐
0-5%	6-14%	15-24%	25-34%	35-44%	45-50%	>50%

51. Did the TIMING of the change orders impact project execution?

No Impact			Some Impact		Highly Impacted (required replanning of project execution plan)	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

52. Did the MAGNITUDE of the change orders impact project execution?

No Impact			Some Impact		Highly Impacted (required replanning of project execution plan)	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

53. Was the scope at the time of completion substantially the same as it was at authorization?

Exactly the Same			Some Changes in Scope		Significant Changes in Scope	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

54. Was the change management process clear to key project team members (see Table 1)?

Extremely Clear		Somewhat Ambiguous			Completely Ambiguous	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

55. Was the change management process followed by key project team members (see Table 1)?

Completely Followed		Somewhat Followed			Not Followed	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

56. How effective was the change management process in controlling cost and schedule growth?

Very Effective		Moderately Effective			Not Effective	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

57. To what extent did Request for Information (RFIs) drive project design changes?

No Impact on Design Changes		Moderate Impact on Design Changes			Caused a High Level of Design Changes	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

58. How remote (distance from highly-populated areas) was the project location?

Not at All Remote		Moderate			Highly Remote	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

59. In general, how populated (rural vs. urban) was the project location?

Low Density (rural environment)		Moderate			High Density (Urban environment)	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

60. What level of infrastructure existed at the site to support the project (e.g., infrastructure is existing utilities (water, electricity, natural gas, etc.) and roads)?

Available Infrastructure		Limited Infrastructure			No Infrastructure/ Greenfield	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

61. What impact did the project location have on the project execution plan?

No Impact on Meeting the Execution Plan			Moderate			Substantial Impact on Meeting the Execution Plan
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

62. Choose a percentage value that best describes the level of modularization (offsite construction) used. This value should be determined as a ratio of the cost of all modules divided by total installed cost. Include all costs for transportation, setting and hooking-up field connections.

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

63. How many different countries worked on the detailed engineering/design phase of the project?

Number: _______ ☐Don't Know

64. How many different countries worked on the construction phase of the project (include both field staff and craft labor)?

Number: _______ ☐Don't Know

65. Were project documents translated into a different language?

☐Yes ☐No

If yes, how many different languages did the official project documents have to be translated into?

Number: _______

66. What were the security requirements for accessing the project construction site?

Low security requirements to enter and protect the site			Some specialized clear needed to enter and protect the site			Specialized clearance to enter the site and protect the site
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

67. How many execution locations were used on this project?

Project Phases	**Number of locations**
Detailed Engineering/Design	Number: _______
Fabrication (bulk materials and equipment)	Number: _______
Construction (including modular assembly yards)	Number: _______

68. What was your company's degree of familiarity with technologies that were involved in each of the following project phases?

	Completely familiar with all technologies			Somewhat familiar with technologies			Not familiar with some technologies
	1	2	3	4	5	6	7
Detailed Engineering/Design	☐	☐	☐	☐	☐	☐	☐
Construction	☐	☐	☐	☐	☐	☐	☐
Operating facility	☐	☐	☐	☐	☐	☐	☐

69. Compared to a typical project for your company, what was the difficulty in system design and integration on this project?

(System is the combination of several pieces of equipment to perform in a particular manner)

	Difficulty						
	Not at all difficult			Moderately difficult			Extremely difficult
	1	2	3	4	5	6	7
Systems	☐	☐	☐	☐	☐	☐	☐

70. How many new systems were tied into existing systems?

Number: ___________ ☐N/A

71. What percentage of project/construction management staff actually worked on the project compared to planned project/construction management staff?

☐	☐	☐	☐	☐
70-84%	**85-99%**	**100-114%**	**115-129%**	**140-145%**

72. What percentage of field craft labor was actually on the payroll at project peak compared to the plan at peak?

☐	☐	☐	☐	☐
70-84%	**85-99%**	**100-114%**	**115-129%**	**140-145%**

73. What percentage of the time were facility/operations personnel available for the project compared to the plan for the project?

☐	☐	☐	☐	☐
70-84%	**85-99%**	**100-114%**	**115-129%**	**140-145%**

74. Was the delivery of permanent facility equipment delayed?

☐No Delay
☐1 Week
☐2-4 Weeks
☐5-8 Weeks
☐9-12 Weeks
☐>12 Weeks

75. What was the frequency of workarounds (work activities out of sequence to continue) because materials were not available when needed to support construction?

No Workarounds		Moderate Number of Workarounds			High Number of Workarounds	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

76. Please rate quality issues with field craft labor during project construction.

No Quality Issues		Moderate Level of Quality Issues			Substantial Number of Quality Issues	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

77. Please rate quality issues with bulk materials during project execution.

No Quality Issues		Moderate Level of Quality Issues			Substantial Number of Quality Issues	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

78. Please rate quality issues with the permanent (tagged) equipment during project execution.

No Quality Issues		Moderate Level of Quality Issues			Substantial Number of Quality Issues	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

79. What was the percentage of craft labor turnover?

☐	☐	☐	☐	☐	☐
0-9%	**10-19%**	**20-29%**	**30-39%**	**40-49%**	**>50%**

80. What was the percentage of project/construction management staff turnover?

☐	☐	☐	☐	☐	☐
0-4%	**5-9%**	**10-14%**	**15-19%**	**20-24%**	**24-28%**

81. What percentage of Bulk Materials were sourced within the project country? (% of Bulk Material Cost)

☐	☐	☐	☐	☐	☐
0-19%	**20-39%**	**40-59%**	**60-79%**	**80-99%**	**100%**

82. What percentage of Permanent (Tagged) Equipment was sourced within the project country? (% of Tagged Equipment Cost)

☐	☐	☐	☐	☐	☐
0-19%	**20-39%**	**40-59%**	**60-79%**	**80-99%**	**100%**

83. What percentage of craft labor was sourced locally? (Within 100 mile radius of Job Site)

☐	☐	☐	☐	☐	☐
0-19%	**20-39%**	**40-59%**	**60-79%**	**80-99%**	**100%**

84. What percentage of the scope was involved with the reuse of existing installed equipment?

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
0%	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**

85. Degree of additional quality requirements?

Construction tolerances exceeded standard practice (industry standard or accepted standard) for the type of project.

Tolerances consistent with Standard Practice			Some Deviations from Standard Practice		Many Tight Tolerances Relative to Standard Practice	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

86. Degree of additional quality requirements?

Specifications for materials exceeded standard practice for the type of project.

No Deviations from Standard Practice		Some Deviations from Standard Practice			Many Deviations from Standard Practice	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

87. At project authorization how did the cost and schedule targets compare to industry/internal benchmarks?

Target

	Target						
	Lower than Industry standard benchmark		At industry Standard		Very aggressive		
	1	2	3	4	5	6	7
Cost target at authorization	☐	☐	☐	☐	☐	☐	☐
Schedule target at authorization	☐	☐	☐	☐	☐	☐	☐

88. What percentage of engineering/design was planned to be completed at the start of construction?

__________ % Engineering/Design

89. What was the actual percentage of engineering/design completed at the start of construction?

__________ % Engineering/Design

90. Please identify any other factors or attributes on this project that contributed to its complexity that may not have been covered in the survey.

____

____

____

Project Complexity

91. Please rate the overall complexity of this project on the scale below:

Very Low Complexity			Moderate Complexity			Very High Complexity
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

92. How does this project's overall complexity compare to the complexity of other projects that your company executes?

Lower level of complexity compared to other projects			Same level of complexity Compared to other projects			Higher level of complexity compared to other projects
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

III. Best Practice Implementation

The intent of this section is to assess relationships between Project Complexity Metrics and their impact on implementation of CII's Best Practices. Each Best Practice is defined by one or three sentences taken from IR 166-3 V2.0, CII Best Practice Guide: Improving Project Performance. The scale is seven point categorical with 1 being "Not implemented at All" and 7 "Very Extensively Implemented."

93. Constructability

Constructability is the effective and timely integration of construction knowledge into the conceptual planning, design, construction, and field operations of a project to achieve the overall project objectives in the best possible time and accuracy at the most cost-effective levels.

To what extent was Constructability implemented on this project?

Not Implemented at All		Partially Implemented		Very Extensively Implemented			Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

94. Team Building

Team building is a project-focused process that builds and develops shared goals, interdependence, trust and commitment, and accountability among team members and that seeks to improve team members' problem-solving skills.

To what extent was Team Building implemented on this project?

Not Implemented at All		Partially Implemented		Very Extensively Implemented			Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

95. Alignment

The purpose of alignment is to focus the energy and talent of the team on a common purpose by developing a common vision of project success and placing personal goals subservient to overall project success. Alignment is defined as "The condition where appropriate project participants are working within acceptable tolerances to develop and meet a uniformly defined and understood set of project priorities."

To what extent was an Alignment Measurement process implemented on this project?

Not Implemented at All		Partially Implemented		Very Extensively Implemented			Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

96. Partnering

Companies may partner in order to achieve specific business objectives by maximizing the effectiveness of each participant's resources. This requires changing traditional relationships to a shared culture without regard to organizational boundaries. The relationship is built on trust, dedication to common goals and the understanding of each other's individual expectations and values. Partnering may be a long term commitment between two or more organizations, as in an alliance, or it may be applied to a shorter period of time, such as the duration of a project.

To what extent was Partnering implemented on this project?

Not Implemented at All		Partially Implemented		Very Extensively Implemented			Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

97. Front End Planning

Front end planning (FEP) is the process of developing sufficient strategic information with which owners can address risk and decide to commit resources to maximize the chance for a successful project. This process provides a comprehensive framework for detailed project planning. FEP is a gated process that focuses on feasibility, concept and detailed scope phases of project development.

To what extent was a Front End Planning process implemented on this project?

Not Implemented at All		Partially Implemented		Very Extensively Implemented			Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

98. Change Management

Change management is the process of incorporating a balanced change culture of recognition, planning, and evaluation of project changes in an organization to effectively manage project changes.

To what extent was Change Management implemented on this project?

Not Implemented at All		Partially Implemented		Very Extensively Implemented			Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

99. Material Management

Materials management is an integrated process for planning and controlling all necessary efforts to make certain that the quality and quantity of materials and equipment are appropriately specified in a timely manner, are obtained at a reasonable cost, and are available when needed. The materials management system combines and integrates takeoff, vendor evaluation, purchasing, expediting, warehousing, distribution, and disposing of materials functions.

To what extent was Materials Management implemented on this project?

Not Implemented at All		Partially Implemented		Very Extensively Implemented			Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

100. Zero Accident Techniques (i.e., Safety)

Zero accident techniques include the site-specific safety programs and implementation, auditing, and incentive efforts to create a project environment and a level of training that embraces the mindset that all accidents are preventable and that zero accidents is an obtainable goal.

To what extent was Zero Accident Techniques implemented on this project?

Not Implemented at All		Partially Implemented		Very Extensively Implemented			Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

101. Planning for Start Up

Startup is defined as the transitional phase between plant construction completion and commercial operations, including all of the activities that bridge these two phases. Critical steps within the startup phase include systems turnover, check-out of systems, commissioning of systems, introduction of feed stocks, and performance testing.

To what extent was planning for Start Up implemented on this project?

Not Implemented at All		Partially Implemented		Very Extensively Implemented			Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

102. Dispute Prevention and Resolution

Dispute resolution techniques include the use of a Disputes Review Board as an alternate dispute resolution process to eliminate the necessity to take disputes to litigation. The Dispute Review Board technique provides a process for addressing disputes in their early stages before the dispute affects the progress of the work, creates adversarial positions, and leads to litigation.

To what extent was a Dispute Review Board implemented on this project?

Not Implemented at All		Partially Implemented		Very Extensively Implemented			Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

103. Quality Management

Quality management incorporates all activities conducted to improve the efficiency, contract compliance and cost effectiveness of design, engineering, procurement, QA/QC, construction, and startup elements of construction projects.

To what extent was Quality Management implemented on this project?

Not Implemented at All		Partially Implemented		Very Extensively Implemented			Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

104. Lessons Learned

A lesson learned is knowledge gained from experience, successful or otherwise, for the purpose of improving future performance. Examples are: a lesson that is incorporated in a work process; a tip to enhance future performance; a solution to a problem or a corrective action; a lesson that is incorporated into a policy or a guideline; an adverse situation to avoid; and collective knowledge of "soon to retire" employees. Lessons learned programs (LLP) involve the people, processes, and tools that support an organization's collection, analysis, and implementation of validated lessons learned.

To what extent was a Lessons Learned Process implemented on this project?

Not Implemented at All		Partially Implemented		Very Extensively Implemented			Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

105. Project Risk Assessment

The process to identify, assess, and manage risk. The project team evaluates risk exposure for potential project impact to provide focus for mitigation strategies.

To what extent was a Risk Assessment implemented on this project?

Not Implemented at All		Partially Implemented		Very Extensively Implemented			Don't Know
1	2	3	4	5	6	7	
☐	☐	☐	☐	☐	☐	☐	☐

106. Are you willing to participate in the follow-up Interview?

☐Yes ☐No

Please send your completed survey to Dr. Stuart Anderson, Texas A&M University, or Dr. Jennifer Shane, Iowa State University, at mailto:s-anderson5@tamu.edu or jsshane@iastate.edu.

THANK YOU FOR PARTICIPATING IN THIS STUDY