IMPROVING ACCURACY

OF PROJECT OUTCOME

PREDICTIONS

by

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A DISSERTATION

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ABSTRACT

Construction industry has found that cost overruns and schedule delays are recurrent problems within the sector. Considerable cost and schedule deviations are issues at the project level that permeate organizations and seriously affect their financial performance. These adverse deviations are evidences that the traditional project control systems fail to predict, promptly and effectively, cost and schedule deviations at completion of capital projects. Even more, it seems that the current assessment methodologies do not inform how well the control system has ensured the expected cost and schedule at completion throughout the life cycle of the project.

The present study inquired into current practices of forecasting and project management to see if the predictability of cost and schedule deviations of construction projects is timely and accurate. Additionally, this research investigated and assed the most relevant change reasons associated to the forecast deviations, as well as, the most critical underlying factors that jeopardize the accuracy and timelines of these predictions. To attain these proposed objectives, a correlation research was mainly designed and complemented with a cross-sectional design. An electronic questionnaire was the primary data instrument adopted to collect the data, which finally, were analyzed by bivariate and ordinal correlations statistical techniques.

The results demonstrated that cost timeliness and predictability –understood as the addition of cost predictability index plus schedule predictability index, were significant predictors of the likelihood of achieving small cost and schedule deviations at project completion, less than 5%. Although there was no evidence enough to demonstrate the statistical significance of schedule timeliness, the study considered and showed its benefit as component of the predictability index. The study identified the most significant change reasons related to forecast increments (cost and schedule) and classified their relevance by owners and contractors. The results demonstrated that change reasons with low frequencies implied high impacts and those with high frequencies implied medium and low impacts. The study showed there are underlying factors that noticeably influence the predictability performance, which must be tracked and controlled to avoid adverse deviations.

DEDICATION

In memory of my father, who shared his search for paths of LIGHT with me, who showed me how to help others through teaching. His physical absence has become my spiritual strength.

February 10, 2013.

LIST OF ABBREVIATIONS AND SYMBOLS

Y	Actual value
Ω_t	All information available at time t
df	Degrees of freedom: number of values free to vary after certain restrictions have
Δ	Delta
E( )	Expected value
χ^2	Chi square
$\hat{Y}$	Forecast
h	Forecast horizon
U	Forecast error
τ	Kendall's Tau-b coefficient
α	Level of significance
p	Probability associated with the occurrence under the null hypothesis of a value
$R_{-/+}$	Rank (negative/positive)
RR	Relative risk
SD	Standard Deviation
SE	Standard Error
Π (*x*)	"Success" Probability
Σ	Sum
t	Time

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CHAPTER 1

INTRODUCTION

Over the last decade, the construction industry has reviewed its current practices of forecasting in order to find solutions to the decline in the capability of its capital projects to deliver value. Recently, the Construction Industry Institute (CII) has found that capital projects of construction organizations have decreased their capability to deliver value when they are in progress. Based on a 64-project study conducted by Mulva and Dai (2012), CII found that, from the early 1990s until the late 2000s, the influence on an average cash flow of owner-projects in progress dropped from 90% to 20% capability. Furthermore, CII found that these capital projects still face cost overruns and schedule delays, which are recurrent problems within the construction sector. In the same study, CII found that nearly 70% of 975 projects showed actual cost and schedule deviations exceeding +/- 10% from their baselines (Mulva & Dai, 2012). Due to these recurrent problems observed, the construction industry has begun to investigate predictability approaches as an alternative to the usual control solutions. These predictability approaches seek to deal with capital projects in environments characterized by noticeable cost and schedule deviations from the initial plans, especially when organizations implement multi-project strategies of management.

Considerable cost and schedule deviations are issues at the project level that permeate organizations. From the owner perspective, these issues seriously affect the financial performance of organizations, especially under scenarios of multi-project management. The multi-project management is a common strategy used by transnational construction companies, specifically when their projects must share constrained resources with others projects in progress (Lova & Tormos, 2001; Payne, 1995). Hence, any noticeable cost or schedule deviation impacts upon the financial performance of an organization either when a project requires more resources than expected to fulfill its scope or when the project tardily releases excess resources. In fact, some authors declare that an effective financial performance at the company level relies upon cash flow projections that depict uncertainty factors and significant cost and schedule deviations of the projects in progress (Park, Han, & Russell, 2005).

In congruence, to maximize the financial resources under these exposed conditions, an organization must identify the amount and timing of individual project inflows/outflows, accurately and promptly (Liu & Wang, 2010; Park, Han, & Russell, 2005). With this end in mind, several authors have proposed integrative methodologies between the project control of cost/scheduling deviations and financial factors of the company to assess and track the overall financial performance (Chen, O'Brien, & Herbsman, 2005; Park, Han, & Russell, 2005; Liu & Wang, 2008, 2009; Maravas & Pantouvakis, 2012). Nevertheless, it seems that the traditional project control systems fail to predict, promptly and effectively, cost and schedule deviations at completion of capital projects. In addition, it seems that the current assessment methodologies do not inform how well the control system has ensured the expected cost and schedule at completion throughout the life cycle of the project. Still, the construction industry faces considerable cost and schedule deviations, either positive or negative, which have the potential to impact on its capital projects.

Recent studies show that both cost overruns and delays are prevalent issues in different types of industry and projects. A study of the Department of Energy (DOE) reported that 8 of 12 projects ($27 billion) showed deviations ranging from $79.0 million to $7.9 billion and 9 of them were behind schedule by 9 months to more than 11 years [United States Government Accountability Office (GAO), 2007]. In the oil and gas industry, for instance, a study showed that cost overruns and schedule delays exceeding +/- 10% from their baselines in 40% of the projects observed (McKenna, Wilcznski, & VanderSchee, 2006). In a study of 78 courthouse construction projects with total cost of $4.5 billion, cost overruns at the design and construction phases were, on average, 17% and 5%, respectively, from 1993 to 2005 (GAO, 2005). In transportation, for example, a study reported that the Indiana Department of Transportation (INDOT) incurred approximately $17 million in cost overruns, 9% of the total amount for all contracts in 2001 projects (Bordat, McCullouch, Sinha, & Labi, 2004). Another study by the DOE showed that 23 of 30 highway and bridge projects expected to cost $100 million had cost overruns between 2 and 211%, of which 15 increased more than 25% percent (GAO, 2003). Likewise, international studies indicated that cost overruns and schedule delays are currently a worldwide issue. In an international study, 258 megaprojects of infrastructure from 20 countries in Europe, Asia, and North America showed average cost overruns of 28% in 86% of them. The global phenomenon of cost escalation was evident across 20 countries ranging from 20 to 45% (Flyvbjerg, Holm, & Buhl, 2003). These facts suggest that there are still underlying issues regarding cost and schedule deviations to be resolved. This is where predictability approaches can play an important role in resolving this growing problem.

To address the misuse of financial resources and the prevalence of adverse cost and schedule deviations, a predictability approach could serve as an effective management tool. Nevertheless, the literature evidences a noticeable lack of research on methodologies of predictability, although, according to Bröchner, Josephson, and Alte (2005), project control and uncertainty appear among the five top trends in construction research for the past 10 years. It has been observed that project management teams need to predict resources at project level to achieve a successful financial performance at company level, when a project portfolio is in execution. In fact, CII stated that an effective predictability of cost and schedule at project level produce good financial results at company level (Mulva & Dai, 2012). Also, it is clear that project management teams need to monitor the progress of the project performance appropriately, in order to anticipate and handle unexpected deviations in budget and schedule at completion. Notwithstanding, based on the overruns and delays showed in previous paragraph, the current control methodologies poorly satisfy this need. The construction industry needs to inquire into current practices of forecasting and project management to see if the predictability of cost and schedule deviations of construction projects is timely and accurate and understand the underlying factors that jeopardize the accuracy and timelines of these predictions.

Do the current project management systems evaluate the performance of project predictability? What are the major characteristics of construction projects with the best performance levels of predictability? What are the major influencing factors on predictability? What are the major change reasons of forecast deviations? The answers to these questions will contribute significantly to solve part of the current problems that the construction industry faces regarding predictability as an effective management tool. The remaining sections of this paper will show the nature of this research, the conceptual framework that supports the proposal of this study, the purpose and scope of this research endeavor, the research design, the data collection instrument, the analysis technique, and finally, a discussion about the findings and their practical and academic merit.

CHAPTER 2

LITERATURE REVIEW

This chapter summarizes the main concepts and gaps of previous studies related to forecasting and its relationship with project management. First, there is a discussion of forecasting understood as a prediction tool; next, a discussion of cost and schedule forecasting, the most common predictions in construction project management; and finally, a discussion of forecasting assessment.

Forecasting as a Prediction Tool

The literature about forecasting shows a wide development in business and economics; therefore, traditionally, the basic definitions of forecasting have been taken from these disciplines. According to Armstrong (2001) and Makridakis, Wheelwright, and Hyndman (1998), forecasting determines future outcomes of uncontrollable and external events that do not rely directly on internal decisions of the company. Furthermore, Makridakis et al. suggested that quantitative and statistical models of forecasting are widely used in business, economics, and finance. Thus, for these models, a forecast referred at time t and projected at time h [$\hat{Y}_{t+h}$] , is a conditional expectation based on all information available at present time t [$\mathrm{E}(Y_{t+h}|\Omega_t)$]. Equation 2.1 and Equation 2.2 below explain this definition.

$$\hat{\mathrm{Y}}_{\mathrm{t+h}} = \mathrm{E}(\mathrm{Y}_{\mathrm{t+h}}|\Omega_{\mathrm{t}}) \tag{2.1}$$

$$\hat{\mathrm{Y}}_{\mathrm{t+h}} \longrightarrow \text{expected value at time } \mathrm{t+h}$$

$$\mathrm{Y}_{\mathrm{t+h}} = \mathrm{E}(\mathrm{Y}_{\mathrm{t+h}}|\Omega_{\mathrm{t}}) + \mathrm{U}_{\mathrm{t+h}} \tag{2.2}$$

$Y_{t+h} \longrightarrow$ actual value at time $t + h$
$\Omega_t \longrightarrow$ all information available at time t
$U_{t+h} \longrightarrow$ forecast error at time $t + h$

In accordance with this definition, the remarkable components of any quantitative and statistical forecasting model are the past values of a subject of interest regarding at time specific, the past forecasting errors, the time horizon, and the relationship with identified influencing factors (see Figure 1).

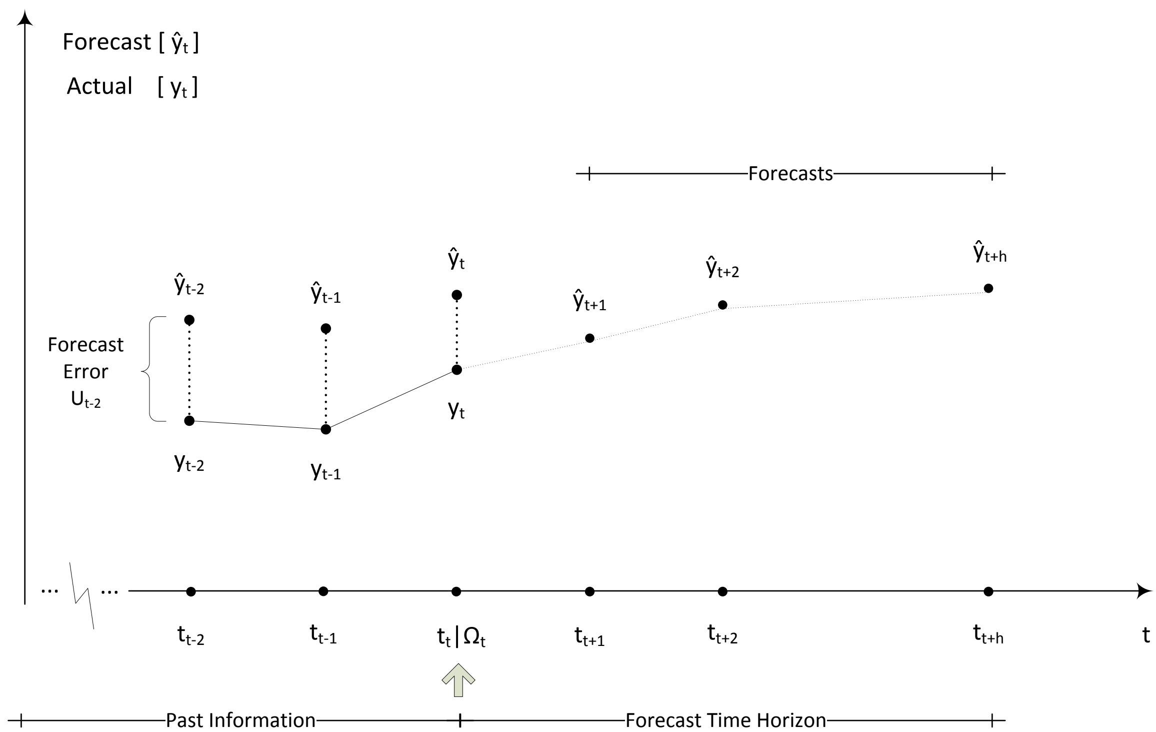

Figure 1. Components of traditional forecasting.

On the other hand, practitioners and academics in construction conceive forecasting as the technique to estimate the expected cost and schedule of the project at completion [Jarnagan, 2009; Lukas, 2008; Project Management Institute (PMI), 2011]. Hence, forecasting is viewed as a function present in activities of project planning, risk management, and control (Kim, 2008; PMI, 2008). In project planning, the forecasting techniques are used for estimating the project cost and schedule. In risk management, the forecasting techniques are used for evaluating the impact of the project risk factors. In control, the forecasting techniques are used for estimating the project cost and schedule at completion. Thus, forecasting has played an important role as a prediction tool that requires the knowledge, experience, and judgment of its forecasters and users for a reliable interpretation of its predictions (Jarnagan, 2009; PMI, 2011). For effects of the present study, predictability and forecasting are indistinct terms that are closely associated to the project control processes. Figure 2 shows the basic components of construction-forecasting of project at completion.

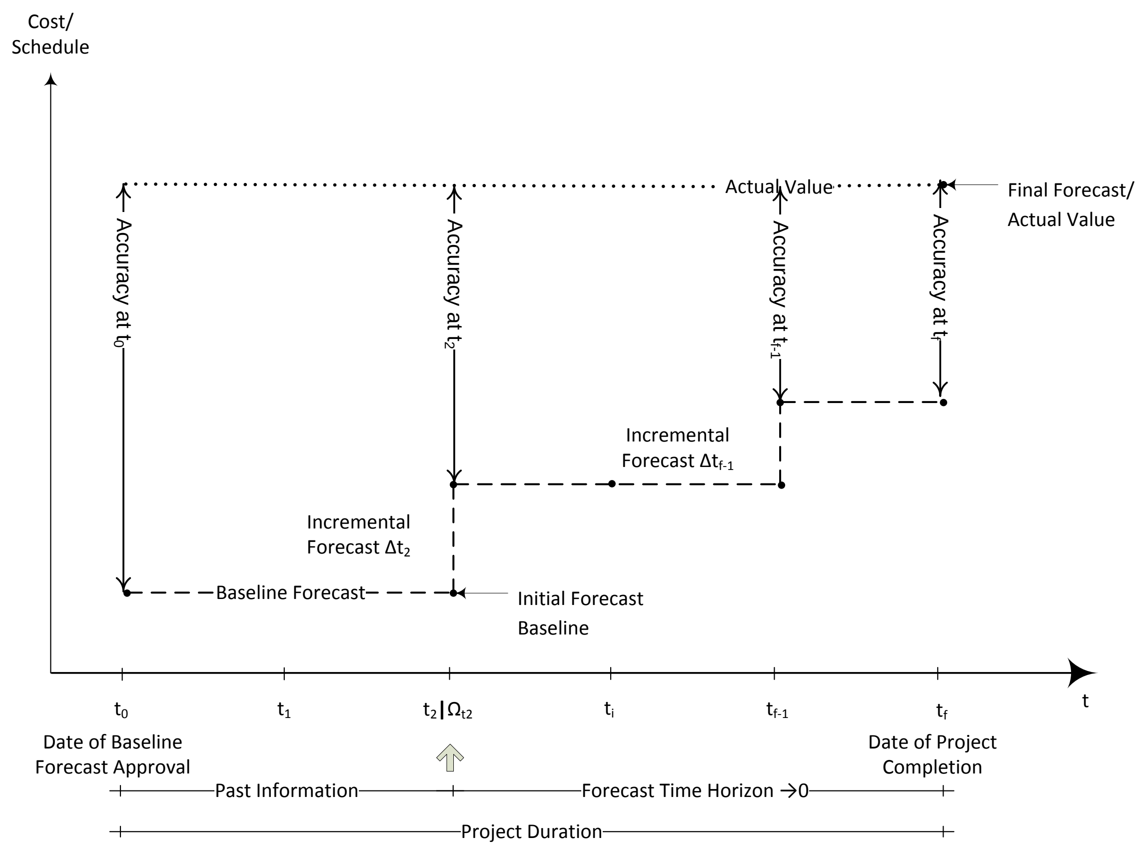

Figure 2. Components of construction forecasting

Forecasting and Project Control

As a function of control, forecasting interrelates with processes of tracking, assessment, and adjustment of expected cost and schedule of projects (Kerzner, 2009; PMI, 2008). In fact, a forecasting system estimates the outcome of cost, schedule, and resources required to fulfill a project scope (O'Brien et. al 2009). For this reason, the function of forecasting plays an important role when the control system requires early estimates of the project cost and schedule at completion. The importance of forecasting as a control function relies on the capability of generating and providing accurate and timely information on the actual project status, so that management teams make decisions properly when needed (Alarcon & Ashley, 1996; Kerzner, 2009; PMI, 2008). Therefore, a good control system must measure the project performance and promptly report any deviations from the initial plan, so that stakeholders obtain reliable financial statements and cash flow projections (Wideman, 1989).

Despite its importance, a recent study has found that construction forecasting faces some problems because often its practices are carried out with no standard industry guide and with limited integration with other project management processes of the company (CII, 2009). This misuse of forecasting methodologies as an effective project management tool for performance assessment jeopardizes the effective decision-making process. For the purpose of the present research, predictability goes beyond a complementary forecasting function associated with monitoring and control processes. Thus, the predictability approaches assess the risk of achieving either the goals of a project or insure that the outcomes of projects are within the expected ranges, as early and accurately as possible.

Construction Cost and Schedule Forecasts

Since the 1980s, construction management systems have focused on how to achieve excellence in the performance of projects through the reduction of cost overruns and schedule delays. The construction industry studies have promoted more accurate and timely controls, performance assessments, and progress measurement methodologies that provide clear reports to assist decision making (Business Roundtable, 1982, 1983). Nonetheless, for the past decades, the control of cost overruns has not improved significantly (Flyvbjerg et al., 2003). From an owner perspective, the significance of predicting cost and schedule performance at the project level is due to the ability to integrate indicators at the aggregate level, such as profitability and productivity, which depict the financial performance of the company (KPI Working Group, 2000).

The cost and schedule performance indicators have evolved from isolated factors at the project level to aggregate measures that relate multiple factors and depict the real condition of the company (Bredillet, Anbari, & Turner, 2008). Notwithstanding, there is no consensus on the standard framework to assess the performance of projects. Some researchers refer to the three traditional indicators: cost, time, and quality (De Marco & Rafele, 2009; Wang, El-Gafy, & Zha, 2010). Others refer to four indicators: cost, schedule, quality, and safety (Bassioni, Price, & Hassan, 2004; Grau, Back, & Prince, 2011); or cost-growth, schedule-growth, incidents and rework (Shields, Tucker, & Thomas, 2003). Even more, there are proposals that refer to more than four performance measures (CII, 2001; KPI Working Group, 2000; Lee, Thomas, & Tucker, 2005). Although the set of project performance indicators is broad and varied, undoubtedly cost and schedule at completion have been the prevalent indicators in every measurement system (Barraza et al., 2004; Chan, Scott, & Lam, 2002).

Monitoring and control cost and schedule are the processes of tracking, managing changes and reporting the statust of the project in order to update the project baselines. The report of the project status must include progress measurements and forecasts at completion . The techniques more common are earned value methodology (EVM) that aids to monitor cost and schedule, the critical path methodology (CPM) that aids to monitor schedule (Kerzner, 2009; PMI, 2008) and Monte Carlo methodologies that aids to evaluate the impact of uncertain events on cost and time at completion (Kim, 2007). The methodology most used is EVM because it measures cost and schedule performance, determines deviations against the baseline, identifies causes of variations, defines corrective actions and provides both a trend analysis and evaluation of estimated cost at completion (PMI, 2008; PMI, 2011). Therefore, this study analyzes and comment this methodology in the following sections.

Forecasting at Completion

The literature about construction forecasting has shown some preference into the use of probabilistic approaches rather than deterministic ones (Back & Bell, 1995; Back, Boles, & Fry, 2000; Barraza, Back, & Mata, 2000; Kim & Reinschmidt, 2010), due to the variability and uncertainty present in all projects (Bowen & Edwards, 1985; PMI, 2008). While deterministic approaches estimate the most likely specific values, probabilistic forecasting involves confidence intervals to better model the variability and uncertainty of projects (Al-Bahar & Crandall, 1990; Kim & Reinschmidt, 2011). For instance, Barraza, Back, and Mata (2004) proposed a probabilistic forecasting for project performance using stochastic S curves. This technique measures the variability of cost and schedule in a project for a given executed work quantity. Although traditionally construction forecasting has focused upon improvement of the outcomes of projects, there is a lack of research about forecasting systems that integrate prediction, risk, and control in a meaningful way.

Currently, EVM is one of the most common techniques to predict outcomes at completion of construction projects (Chen & Zhang, 2012; Kim, Wells, & Duffy, 2003). EVM is a quantitative technique that involves variance analysis and performance indexes—cost performance index and schedule performance index—to identify any deviation and its effects on cost and schedule at completion (Jarnagan, 2009; Kim et al., 2003; Lukas, 2008; PMI, 2008, 2011).

At its early stages, EVM research focused on achieving the accuracy of deterministic approaches. Some proposals suggested the integration of cost and schedule performance at work package level with complementary methodologies to solve issues regarding the assumption of the prevalence of past performance and overly optimistic predictions (Howes, 2000; Rasdorf & Abudayyeh, 1991; Ruskin, 2004). Other proposals suggested the differentiation between value- and non-value-generating work (Kim & Ballard, 2002). Although these early efforts focused on some technical aspect, further attempts focused on more integrative solutions such as diagnosis of cost and schedule deviation causes, forecasting of deviation impacts, identification of constraints, and determination of activities under risk for example (Diekmann & Al-Tabtabai, 1992; Vanhoucke, 2009). These trends evidenced a searching for methodologies beyond forecasting techniques that assess the contribution of the forecasting processes to management systems.

Referred to as a prediction methodology, EVM has shown advantages and disadvantages. Within the advantages, EVM is the most common methodology to predict cost and schedule at completion (Chen & Zhang, 2012; Kim et al., 2003). The benefit of this methodology is to produce information and predict the outcomes of projects so that management teams take corrective actions in response to identified adverse cost and schedule deviations (Lavingia, 2004; Putz et al., 2007). Disadvantages of this methodology include overly optimistic views and inaccurate assessment of forecasts at completion (Chen & Zhang, 2012; Kim et al., 2003; Vargas, 2003); schedule performance indicators are not reliable and are essentially erroneous over entire project life (Lipke, 2005); EVM does not prevent adverse cost and schedule deviations, it only provides an early warning mechanism of project issues (Jarnagan, 2009); EVM lacks the concepts of flow and value generation; and managers can manipulate work sequences or release work assignments (Kim & Ballard, 2002).

In spite of valuable research about EVM, the current methodologies only shows the project budget, cost and schedule to date, remaining budget and schedule, and reactive forecasts, which result in insufficient information to warn of potential problems promptly. There is a noticeable need to find methodologies that reliably report the state of the project at completion as accurately and early as possible. It needs to investigate how well a project management anticipates future problems. It is necessary to go from methodologies of control-assessment to methodologies that take into account predictability as an indicator of the project status at completion.

Forecasting Assessment

Although there are some advances in research looking for more accurate and timely control, owners of projects still complain of lagging and inaccurate predictions which might jeopardize the decision making. In fact, some researchers argue that inaccurate and late predictions may lead to lost opportunities, wasted development effort, and lower than expected returns (Oberlender & Trost, 2001).

Several critical problems arise when monitoring systems tardily and erroneously detect potential problematic changes, which adversely affect cost and schedule performance (Backes & Ibbs, 1994; Oberlender & Trost, 2001). Therefore, predictability as a performance indicator for a project that takes into account the forecast's timeliness, its accuracy, and its impact on cost and schedule at completion, might be an alternative solution to identify the factors that influence cost and schedule deviations in a project. In consequence, achieving admissible cost and schedule deviations at completion relies on predictability; predictability relies on timeliness and accuracy.

Traditional Forecasting Assessment

Traditionally, the performance assessment of forecasting has relied on the accuracy of the quantitative or statistical models. Therefore, the former prediction errors play an important role in the improvement of the accuracy of the subsequent expected values (Wacker & Sprague, 1995). Accuracy is viewed as a measure of the prediction error associated with the forecasting method, which has technical and practical connotations (Armstrong, 2001; Carbone & Armstrong, 1982; Makridakis et al., 1998; Mahmoud, 1984; Walden, 1996; Wilson & Keating, 2002). According to Makridakis et al. (1998), the technical connotation of accuracy is related to a measure that indicates how well a prediction model reproduces an actual situation and its historical data. Furthermore, Makridakis et al. argued that the practical connotation is related to a measure of the effect of the prediction on the company's decision making. For instance, it is necessary to stress the technical and practical connotations of construction forecasting. The performance of forecasting might be based on the historical accuracy of its predictions and the impact of its forecast on the project outcomes such as the cost and schedule of the project at completion.

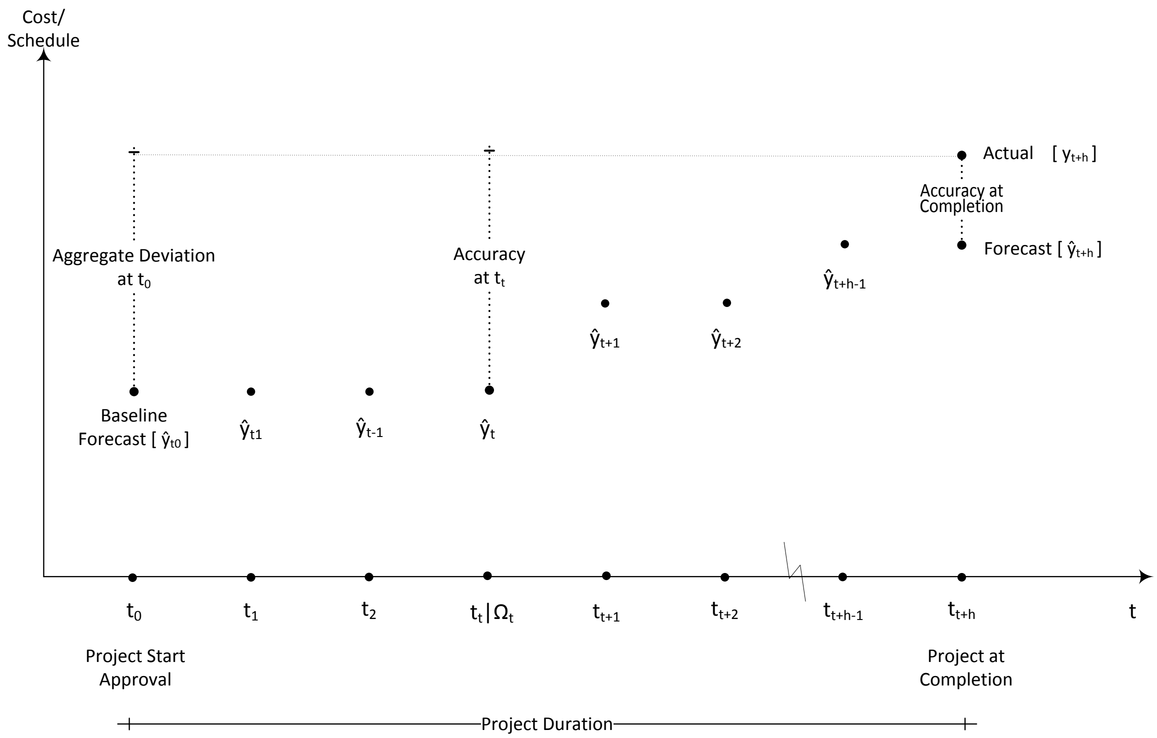

Figure 3. Forecasting accuracy of outcomes at completion.

Based on the forecast accuracy, the actual value of the project at completion is the referent to assess any forecast. Technically, accuracy is the difference between the actual project cost (or schedule) at completion and the forecast at any time *t*, across the life cycle of the project. Additionally, a practical connotation of accuracy might refer to the aggregate deviation (cost overrun or schedule delay), which is the difference between the actual project cost at completion and the forecast at time 0 or baseline. This practical connotation might indicate the efficacy of the forecasting warnings related to the expected cost and schedule at completion (see Figure 3). Nevertheless, these measures are indicators that inform little or nothing about the efficiency of the predictability and how early adverse aggregated deviations were detected.

Construction Forecasting Assessment

As in other disciplines, the performance of construction forecasting has relied on the accuracy and reliability of its models (Bowen & Edwards, 1985; Park et al., 2005). Therefore, some researchers advocate technical measures of performance based on prediction model accuracy (Klimberg, Sillup, Boyle, & Tavva, 2010; Lowe, Emsley, & Harding, 2006; Zwikael, Globerson, & Raz, 2000). Others recognize the need of a practical assessment that involves other indicators, such as timeliness. Alarcon and Ashley (1996) recognized the relevance of any forecasting system within a construction project control because of the capability of generating and providing accurate and timely information on the actual project status.

Besides accuracy, timeliness is a critical factor of successful predictability. There is a strong relationship between timely forecasts, decision-making processes, and prompt corrective actions within a management system (Baar & Jacobson, 2004). Timely forecasts are important to communicate issues and trends prior to the events occurring, so that management teams minimize and/or avoid cost overruns and schedule delays (Hamilton, 2004). For the last decade, researchers have sought new models of forecasting assessment that involve indicators other than accuracy. For instance, Teicholz (1996) proposed accuracy, timing, and consistency as criteria for assessing forecasting. For Teicholz, accuracy is the area enveloped between the actual final cost and the forecasts of cost at completion through the project duration, while timeliness is the accuracy level at the first 50% of the project duration, and consistency is a dispersion measure of the forecasts computed by the square of the deviations from the true forecast final cost. Kim (2008) based the performance evaluation of forecasting on accuracy, timeliness, and reliability. Accuracy is the traditional forecasting error and timeliness and reliability are warnings system with evaluations based on risk and probabilities. Anjaneyulu (2009) documented a new model based on a practical connotation of the forecast accuracy, which is a measurement of the forecast variance.

The proposals suggested for timeliness, so far, present some shortcomings due to the complexity of measuring time and the need for a practical and reliable measure. These shortcomings bring the following questions about: How well has the project management system anticipated future problems? How does current forecasting assessment convey the benefit or impact of early predictions? There is no proper measurement that responds consistently to these questions. The present study proposes to assess predictability based on timeliness and a practical accuracy measure. In this offered proposal, timeliness is a technical measure of the model accuracy linked to time. Timeliness is the estimation of the shadowed area enveloped by the actual project value line and the updated line of the forecast baseline. Complementarily for this proposal, a practical connotation is the aggregate deviation that depicts the impact of any deviation forecast on the value at completion. The aggregate deviation is the difference between the actual project cost at completion and the first forecast (see Figure 4).

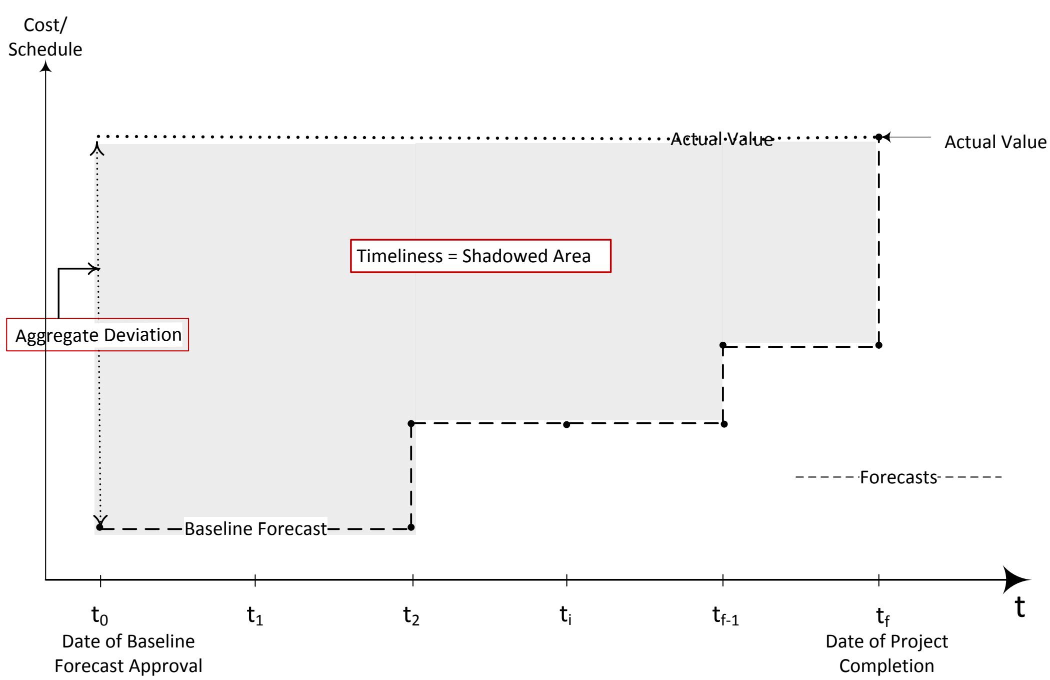

Figure 4. Accuracy and timeliness of construction forecasting.

CHAPTER 3

RESEARCH AIM AND METHODOLOGY

This chapter states the problem investigated in this study. Afterwards, the chapter explains the proposed solution, as declared by the aims, specific objectives, and scope of the study. Finally, this chapter describes the research methodology undertaken to achieve the proposed objectives.

Problem Statement

In spite of valuable research about uncertainty and project control for the last two decades (Bröchner et al., 2005), the literature review showed some gaps in the forecasting assessment methodologies (Anjaneyulu, 2009; Kim, 2008; Teicholz, 1996). It seems that the current methodologies result in insufficient information to warn of potential problems in an easy and fast manner. Hence, this study adopted a predictability approach to define the problem statement as follows.

The construction industry lacks predictability tools that quickly diagnose deviations of cost and schedule of projects at completion, in a promptly, accurate, and reliable manner. Due to this lack of such predictability tools, the construction industry still faces difficulties in avoiding adverse deviations. What is more crucial is that the current project management inefficiently reports the timeliness and effectiveness of predicting these noticeable deviations at completion, whether favorable or unfavorable.

Research Aim

To solve the problem stated above, this study aimed to measure the predictability of the cost and schedule of projects at completion and to analyze the nature of their forecast deviations. The method specifically measured the performance of predictability based on the timeliness and the accuracy of their forecasts. This measurement was based on the method proposed by CII in a recent study (Back & Grau, 2013). Additionally, the present study identified the relevant factors that influenced these measures of predictability. With these findings, this study might offer project management teams valuable insights to diagnose adverse deviations, as timely and accurately as possible.

Specific Objectives

As specific objectives, this study aimed to:

1. assess the predictability index for construction projects, based on timeliness and accuracy of cost and schedule forecasts at completion;

2. investigate and assess the change reasons of deviations in cost and schedule forecasts of project at completion; and

3. investigate and assess the underlying factors that influence the predictability of projects, specifically the timeliness and accuracy of cost and schedule forecasts at completion.

Research Scope

Being aware of the complexity of the problem, this study delimited its scope based on the following considerations:

First, this study assumed that projects analyzed properly implemented front-end planning (FEP) practices. Although ineffective FEP practices may influence the predictability of every project performance measure, notwithstanding, this study focused on project predictability itself rather than FEP issues.

Second, this study evaluated the predictability of cost and schedule deviations at project completion. Other project outcome measures such as safety, quality, operability, and stakeholder satisfaction were considered but not included in this study. These measurements were not included due to the non-standardized and the qualitative nature of the assessments that offered a noticeable complexity when comparing the performance of predictability between projects. In consequence, this study only inquired about cost and schedule forecasts at completion.

Third, this study analyzed the performance of cost predictability and schedule predictability at project completion, from the project authorization to the project completion dates. Due to the intrinsic nature of capital projects, at phases before authorization date, there is a noticeable variability of project definition and consequently of the expected accuracy of projected cost and schedule at completion. Therefore, in order to accomplish the proposed objectives realistically, this study analyzed the performance of predictability after project authorization.

Fourth, this study used a method based on a recent proposal of CII to measure predictability through timelines and accuracy (Back & Grau, 2013). Also, the sample for this study was drawn from CII member companies. These companies supplied data on projects that were completely executed. Owners and major providers of engineering, construction, and maintenance services comprised the sample for this study.

Finally, this study investigated predictability as a comprehensive management process rather than as a quantitative forecasting technique. Quantitative forecasting techniques have been studied and reported in the literature considerably (Back & Bell, 1995; Back et al., 2000; Barraza et al., 2000; Kim & Reinschmidt, 2010). Nevertheless, the prediction of cost and schedule at completion is a management process that requires an understanding beyond the deterministic and stochastic approaches to generate forecasts. Thus, besides the predictability measurement, this study identified the major reasons and factors that influenced the predictability performance of the projects in study.

Research Methodology

To attain the proposed objectives, a correlation research was mainly designed and complemented with a cross-sectional design. Next, an electronic questionnaire was the primary data instrument adopted to collect the data. Finally, bivariate and ordinal correlations statistical techniques were mainly used to analyze the data. Figure 5 shows the major steps that comprised this research methodology, which are explained as follows.

Because a correlational design seeks to explain the relationships among variables and to estimate their extent of association (Creswell, 2005), this study mainly chose this type of research to establish relationship evidences between predictability indices and variables of interest. Thus, all projects in this study were assessed based on predictability indices. Additionally, this correlation design was complemented by a cross-sectional design that collects data once, with no-time reference for the data analysis, and focuses on existing differences between groups of the sample (De Vaus, 2001). Thus, all projects in this study were projects completely executed and the data depicted a condition at completion or an overall condition of the project. Moreover, this study allowed the researcher to explain the relationships between predictability and change reasons, the relationships between predictability and influencing factors, and to analyze these relationships by group of projects. In fact, this study explained the findings between two groups of projects: owner-projects and contractor-projects and the differences between two groups of project predictability performance: best predictor projects and poor predictor projects. For more information in detail about comparison between good and poor predictors, see Back and Grau (2013).

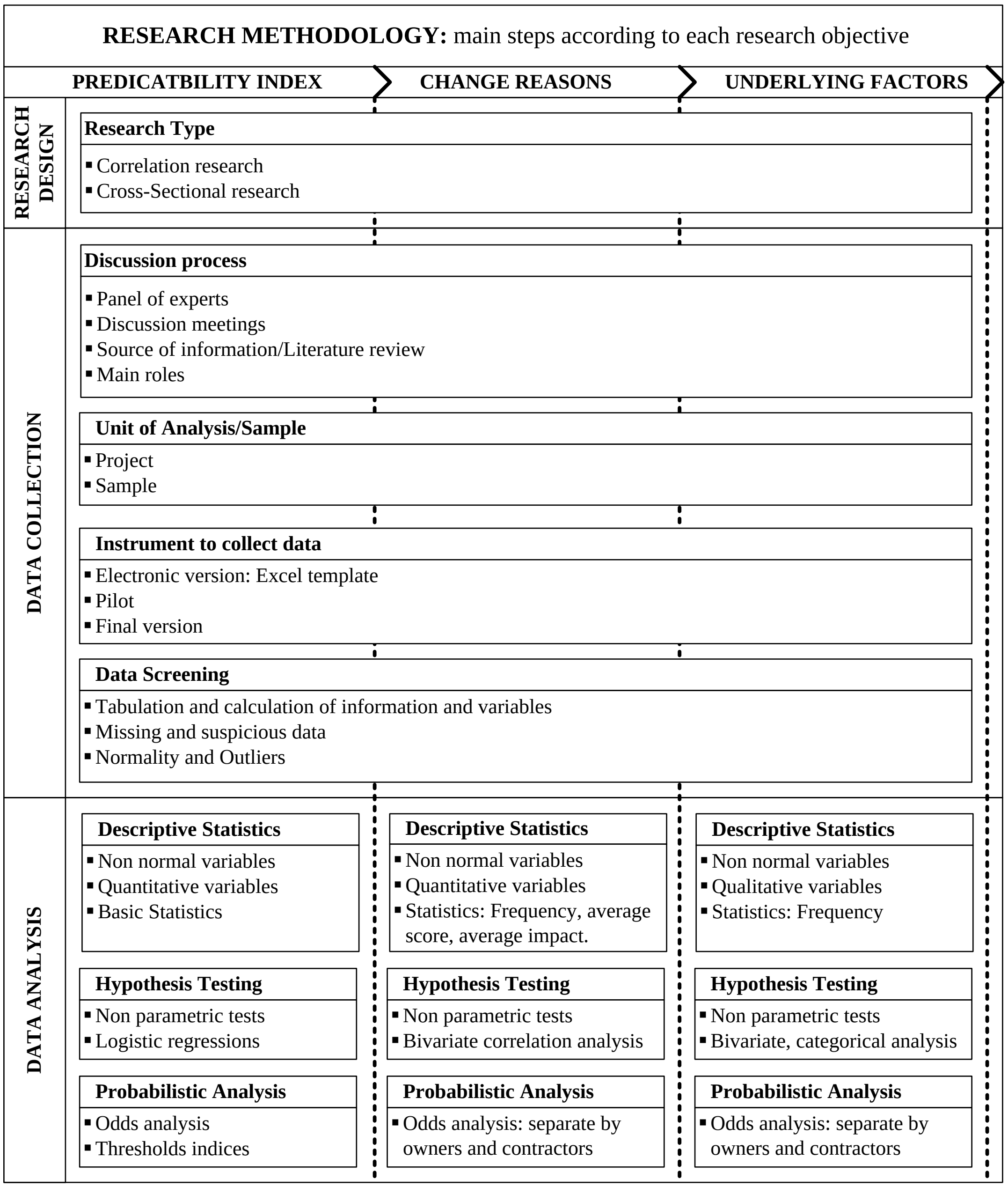

Figure 5. Major research methodology steps.

For the data collection, first, a discussion process was undertaken to define the main concepts and variables that were addressed in the study; to validate the instrument to collect data and the preliminary findings; and to solve any ambiguity on the concepts and variables that arose. A panel of 20 experts, two faculty members from The University of Alabama and 18 practitioners from the CII companies undertook this process of design and validation; through a 7-month discussion period, the panel of experts held three face-to-face meetings and monthly phone call meetings. The source of information that fed this process was taken from a comprehensive literature review that compromised CII, construction management, and business forecasting literature, which has been reference through this dissertation.

Next, a mixed procedure of data collection was undertaken. Quantitative and historical data of cost and schedule deviations were collected to measure the predictability index. As a result from the discussion process the following variables were defined for this study, slightly adapted from the CII study of predictability (Back & Grau, 2013): predictability (P), cost predictability index (CPI), schedule predictability index (SPI), cost timeliness (CT), schedule timeliness (ST), cost aggregate deviation (CAD), and schedule aggregate deviation (SAD). Also, quantitative data were collected to depict the reasons which were rated on a 10-point scale and associated with the forecasting deviations. Another result from the discussion process was a list of 36 potential change reasons classified in 11 categories and the definition of change reason. A change reason is a factor associated to either a scope change, which is a fundamental change to the sanctioned scope; a forecast deviation, which is a modification of the sanctioned funding, scope, design, or approach; or a trend, which is factor influencing on forecast cost and schedule but not covered by scope changes and deviations. Finally qualitative cross-sectional data at project completion were collected to depict the characteristics and conditions of the projects, forecasting practices, management practices, and human factors. As result of the discussion process, over 60 potential influencing factors were defined to be included in the collecting instrument. Chapter 4 explains the definition and operationalization of variables in more detail.

Once the variables to be collected were defined, the unit of analysis and the sample were defined within the discussion process. The unit of analysis for this study was the project. CII member companies supplied data of relevant projects completely executed. Delegates from eight owner organizations and from seven major providers of engineering, construction, and maintenance services sent projects' information to compromise the sample. The sample resulted in 135 projects from the 147 projects submitted initially, due to due to irrelevant information presented (i.e., values of zero in timeliness, and aggregated deviation).

Next, an electronic version of questionnaire was administered to collect detailed information. This step, lasting 1 month, began with the design and test of a pilot questionnaire with the participation of seven experts who sent information about 10 projects. The electronic version was designed on a *Microsoft*© *Excel*© version 2010 spreadsheet and the process of collecting took 3months. Chapter 4 explains the instrument design process in more detail.

Once the information was collected, the data were tabulated and the predictability indices were computed. The information was organized using *Microsoft*© *Excel*© version 2010 and *IBM*© *SPSS*© version 19. A review of missing and suspicious data was undertaken, and then an analysis of normality and outliers was carried out, where those data greater 3Z were dropped. The variables showed to be non-normal and the different options to transform them were not of practical use.

Finally, after defining and collecting the information, a bivariate and categorical correlation analysis was undertaken. These statistical analysis techniques allowed finding evidences of association between variables rather than of causality, because of the nonexperimental nature of this research (Pedhazur & Schmelkin, 1991). Additionally, a categorical correlation analysis of frequency was undertaken, which allowed predicting projects that met predetermined conditions using logistic regression models (Agresti, 2007; Montgomery, Peck, & Vining, 2012; Pampel, 2000; Tabachnick & Fidell, 2013). In fact, the study identified the significant components of the predictability index, the significant change reasons of forecast deviations, and the significant influencing factors on predictability.

The data analysis was conducted in three basic steps. First, this analysis described the characteristics of the involved variables. The study described the variables involved in the predictability index and its components; next, the variables involved in the relationships between change reasons and predictability; and finally, the variables involved in the relationships between influencing factors and predictability. Second, this analysis determined how well the collected sample data fit the hypothesized relationships of predictability. Consequently, the study accomplished an overall test of the fit of the proposed index of predictability. Next, the study identified the significant and relevant relationships between the list of potential change reasons and the index of predictability. At the significance level $\alpha = 0.05$, this study used a Kendall's tau-b coefficient (τ_b), a nonparametric measure of association employed with ordinal data, for rank-order variables often used with but not limited to 2-by-2 tables . Tau-b requires binary or ordinal data (Agresti, 2010). For the level of association, this study utilized effect sizes given by De Vaus (2001). A coefficient between 0.90 and 0.99 indicated a near perfect relationship; a coefficient between 0.70 and 0.89, a very strong relationship; a coefficient between 0.50 and 0.69, a substantial relationship; a coefficient between 0.30 and 0.49, a moderate relationship; a coefficient between 0.10 and 0.29, a low relationship; and finally, a coefficient between 0.01 and 0.09 indicated a trivial relationship. Later, the study identified the significant relationships and differences of factors that influenced on the index of predictability. Third, the study undertook a probabilistic analysis with the significant components, reasons, and factors to determine the level of influence or impact of each one on the predictability performance. Chapter 5, Chapter 6, and Chapter 7 explain the analysis for the predictability index, change reasons, and influencing factors, respectively.

CHAPTER 4

DATA COLLECTION

This chapter describes the unit of analysis and the sample used in this study. Afterward, the chapter details the instrument and procedure used in the data collection. Next, a definition of the variables used in the study is given. Finally, this chapter describes a data screening procedure undertaken before conducting the statistical data analysis.

Unit of Analysis and Sample

The unit of analysis for this study was the project. CII member companies supplied data of relevant projects completely executed. Delegates from eight owner organizations and from seven major providers of engineering, construction, and maintenance services made up the sample. The sample resulted in 135 projects from the 147 projects submitted initially, due to irrelevant information presented (i.e., values of zero in timeliness, and aggregated deviation). In all, 135 surveys (data for individual projects) were fully completed and analyzed. The composition of the sample was 70 contractor-projects (52%) and 65 owner-projects (48%). The sector of affiliation had a distribution of 66 (49%) public projects, 64 (47%) private projects, and 5 (4%) classified as both. The Total cost installed of the sample was $20,888 MM and the total weeks of the sample was 14,998 weeks. A broader demographic composition of the sample is shown in a further section of this chapter.

Collecting Instrument and Procedure

A structured questionnaire collected relevant information for each of the 135 projects in the database, regarding the actual project forecasts, the pre-identified change reasons, and the pre-identified factors that might influence the project predictability performance, which were determined through a definition process with a panel of experts. Three face-to-face meetings and six phone-call conferences, scheduled along a 7-month period, determined the procedure to collect the relevant data and discussed and approved the design of the questionnaire.

Regarding the actual project forecasts, the study obtained data about the original authorization estimates for cost and schedule. The authorization value represented the baseline condition as approved by the project sponsor. Incremental adjustments to project forecasts were nearly always made during project execution and these historical data were captured for each project in the data set. Final cost and schedule values at completion were also obtained. The numerical forecast data were normalized in percentage, which is explained in the next section within this chapter, for all projects in the database in order to facilitate their comparison and statistical analysis as part of the research process to account for differences in scale and magnitude. To perform this comparison, this study defined predictability indexes, explained in the definition of variables section.

It was important for the study to differentiate the database of projects by owners and contractor and by predictability performance. The process of definition for reasons and factors was based on a literature review from CII, construction management, and business forecasting literature, during a 7-month period of discussion with a panel of 20 experts. The pre-identified change reasons were defined as those events that either triggered changes in cost and schedule predictions or affected the accuracy of such project predictions. An initial brainstorming for collecting reasons and categorizing them was undertaken; next an analysis of key terms helped to identify the most important and relevant reasons, which were compared with the literature review findings. Later, from an initial list, the final and filtered list ended in 36 potential change reasons grouped into 11 categories. Similarly, a process of identification of influencing factors ended in over 60 potential factors, grouped in four sections, project characteristics, forecasting practices, management processes, and human factors.

Finally, the panel of experts designed a pilot survey with six sections and over 60 structured questions. The researcher administered the pilot survey and the final version of the survey by an electronic questionnaire. The pilot design and test took 1 month with the participation of seven experts who sent information about 10 projects. To see more in depth the procedure to build a pilot of surveys, see Pedhazur and Schmelkin (1991). The electronic version was designed on a *Microsoft*© *Excel*© version 2010 spreadsheet with the use of developer tools to create the collecting forms (Etheridge, 2010). The process of collecting data from the different CII member companies took 3 months. The digital form warranted a greater feasibility of collecting information; thus, filling the form was more accurate and quick. After 1 month of revision and discussion upon the pilot version, the final version had four qualitative sections and two quantitative sections. The qualitative sections included a) project characteristics, b) forecasting practices, c) management practices, and d) human factors (i.e., information regarding project team behaviors, organizational issues, and company culture). The quantitative section included project cost forecasts and project schedule forecasts with their associated change reasons. Table 1 summarizes the number of questions per section and Appendix A shows the form of each section of the questionnaire.

Table 1

Sections and Questions of the Questionnaire

Section	Aim	Related to	No Questions	Type of Response
Project characteristics (17 questions)	To collect data on potential underlying factors (Specific Objective 3)	Type of company	3	Qualitative
		Type of project	9	Qualitative (7) & Quantitative (2)
		Type of contract	5	Qualitative
Forecasting practices (20 questions)[1]	To collect data on potential underlying factors (Specific Objective 3)	Team	6	Qualitative
		Information	2	Qualitative
		Process	6	Qualitative
		Interrelations	5	Qualitative
Management processes (20 questions)	To collect data on potential underlying factors (Specific Objective 3)	Project planning	6	Qualitative (5) & Quantitative (1)
		Information management	4	Qualitative
		Change management	2	Qualitative
		Risk management	4	Qualitative (2) & Quantitative (2)
		Project control	2	Quantitative
		Execution practices	2	Qualitative
Human factors (15 questions) [2]	To collect data on potential underlying factors (Specific Objective 3)	Explicit influences	4	Qualitative
		Implicit influences	4	Qualitative
		Reactions	3	Qualitative
		Work climate & culture	2	Qualitative
Cost forecast deviations	To collect data on authorized forecast deviations (Specific Objective 1)	Authorized change	Logs	Quantitative
Schedule forecast deviations		Authorized change	Logs	Quantitative
Change reasons (36 reasons)	To collect data on the change reasons of authorized forecast deviations (Specific Objective 2)	Owner/Scope change	5	Quantitative
		Legal requirements	4	Quantitative
		Engineering design	3	Quantitative
		Work planning/execution	5	Quantitative
		Startup/commissioning	1	Quantitative
		Control System	6	Quantitative
		Suppliers/Procurement	5	Quantitative
		Economic conditions	3	Quantitative
		Legal/Social conditions	3	Quantitative
		Natural threat	1	Quantitative

Notes: [1] The question 2.1 was an open type question.
[2] The questions 4.10 and 4.15 were dropped.

Definition of Variables

Operationally, this study defined each qualitative variable and determined its type and scale. Appendix B shows the definition and description of each variable for the qualitative sections, project characteristics, forecasting practices, management practices, and human factors. Likewise, the study defined operationally the quantitative variables, and determined the estimation procedure and the standardized method for each one of them, as follows. The study obtained the original authorization values or estimates for cost and schedule per project, which represented the baseline condition or the original plan as approved by the project sponsor. Incremental adjustments or revisions to project forecasts are nearly always made during project execution and these historical data were captured for each project in the data set. Final cost and schedule values at completion were also obtained. Utilizing the forecast logs provided in the data collection, the predictability index allowed measurement of each forecast of project with respect to cost and schedule. All project cost and schedule values obtained in the data collection were normalized on a percentage base as part of the research process to facilitate their comparison and statistical analysis. The definition of the main variables used in this study is given in the remaining part of this section, which is based on the basic components of predictability index shown in Figure 6.

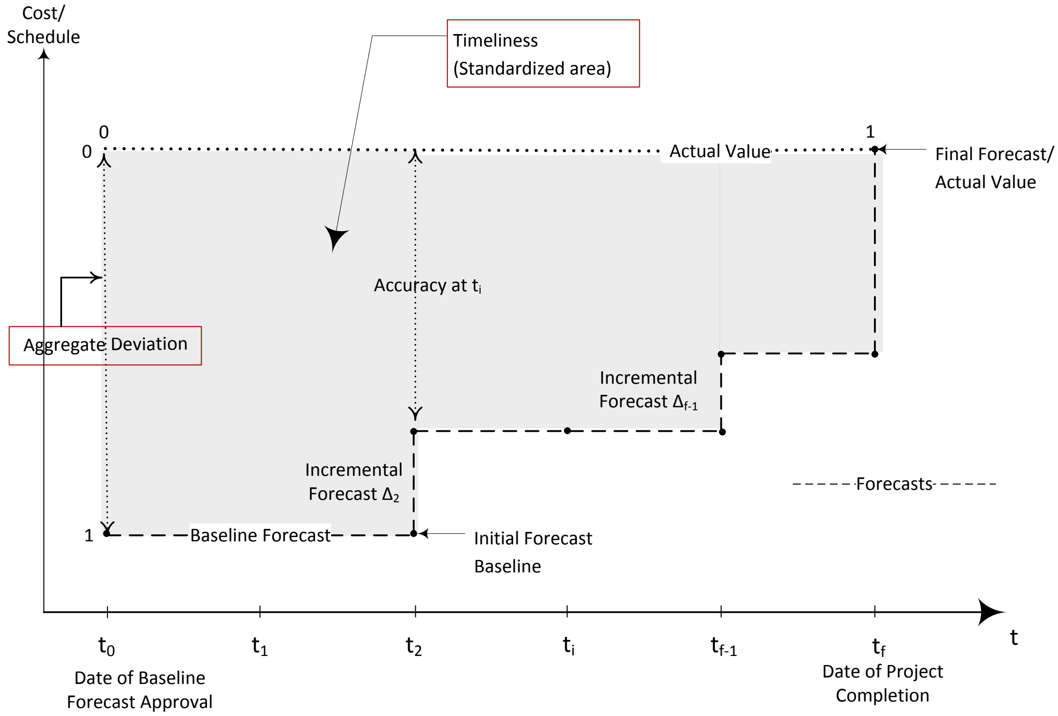

Figure 6. Predictability index components.

As a clarification note, the formulas indicated in this study differ from Back's and Grau's (2013) proposal, when computing the cost and schedule aggregated deviations. For the purposes of this research, the deviation is measured regarding the actual values, according to the definition of forecasting performance measures based on accuracy given by authors such as Amstrong (2001), Carbone and Armstrong (1982), Chase (1996), Mahmoud (1984), Makridakis et al. (1998), Klimberg et al. (2010), Lowe, Emsley and Harding (2006), and Zwikael et al (2000). While the proposal of Back and Grau (2013) takes the deviation as a measure regarding the first baseline, as the traditional deviation in cost and schedule control approaches. Thus, the formulas used for this research are:

Predictability (P): It is an indicator of the project prediction performance. This indicator uses the index of predictability of cost and schedule at completion as a performance indicator.

$$\text{Predictability} = \text{Cost Predictability Index} + \text{Schedule Predictability Index} \qquad (4.1)$$

Quantitative Variables Related to Cost Predictability Index

This section defines the quantitative variables and expressions utilized to explain the cost predictability index.

Cost Predictability Index (CPI) is an indicator that measures the cost prediction performance. This index tells how effective it was the process of ensuring that the cost forecast deviations were within the admissible range and that the impact of the aggregate deviation on the project at completion was the minimum possible. Furthermore, this index informs how early it was the identification of these deviations. Values closer to zero indicated preferred forecasting performance.

$$\text{Cost Predictability Index} = (\text{Cost Timeliness})(\text{Cost Aggregate Deviation}) \qquad (4.2)$$

Cost Timeliness (CT) is the normalized measure of the time-moment to advice of a deviation that adversely influenced the health of the project. It is a measure of efficiency of the project predictability. Timeliness indicated how quickly the forecasting system determined a relevant incremental forecast of cost.

$$\mathrm{CT} = \sum\nolimits_{0}^{n} \left(\frac{|\text{Actual cost at completion} - \text{Forecast}_t|}{\text{Actual cost at completion}} \right) \left(\frac{\text{Period}_t}{\text{Project duration}} \right) \qquad (4.3)$$

n: the number of forecasting periods along the total duration of the project.

Cost Aggregate Deviation (CAD) is the sum of the incremental forecasts formally registered, or, the normalized deviation between the actual cost at completion and the initial forecast or baseline. This is a measure of effectiveness of the predictability and/or the monitoring processes of the cost forecasting.

$$\mathrm{CAD} = \sum\nolimits_{0}^{n} \text{Incremental forecast } \Delta_t \qquad (4.4)$$

n: the number of forecasting periods along the total duration of the project.

Or

$$\mathrm{CAD} = \frac{|\text{Actual cost at completion} - \text{Initial forecast at completion}|}{\text{Actual cost at completion}} \qquad (4.5)$$

Quantitative Variables Related to Schedule Predictability

This section defines the quantitative variables and expressions utilized to explain the schedule predictability index.

Schedule Predictability Index (SPI) is an indicator that measures the schedule prediction performance. This index tells how effective the process of ensuring that the schedule forecast deviations were within the admissible range was and that the impact of the aggregate deviation on the project at completion was the minimum possible. Moreover, this index informs how early the identification of these deviations was. Values closer to zero indicated preferred forecasting performance.

$$\text{Schedule Predictability Index} = (\text{Schedule Timeliness})(\text{Schedule Aggregate Deviation}) \tag{4.6}$$

Schedule Timeliness (ST) is the normalized measure of the time-moment to advise a deviation that adversely influenced the health of the project. It is a measure of efficiency of the project predictability. Timeliness indicated how quickly the forecasting system determined a relevant incremental forecast of schedule.

$$\mathrm{ST} = \sum_{0}^{n}\left(\frac{|\text{Actual schedule at completion} - \text{Forecast}_t|}{\text{Actual schedule at completion}}\right)\left(\frac{\text{Period}_t}{\text{Project duration}}\right) \tag{4.7}$$

n: the number of forecasting periods along the total duration of the project.

Schedule Aggregate Deviation (SAD) is the sum of the incremental forecasts formally registered, or, the normalized deviation between the actual schedule at completion and the initial forecast or baseline. This is a measure of effectiveness of the predictability and/or the monitoring processes of the schedule forecasting.

$$\mathrm{SCAD} = \sum_{0}^{n}\text{Incremental forecast } \Delta_t \tag{4.8}$$

n: the number of forecasting periods along the total duration of the project.

or

$$\mathrm{SAD} = \frac{|\text{Actual schedule at completion} - \text{Initial forecast at completion}|}{\text{Actual schedule at completion}} \tag{4.9}$$

Quantitative Variables Related to Change Reasons

As mentioned earlier, along a 7-month period of discussion, a panel of experts identified 36 cost and schedule potential change factors (see Table 2).

Table 2

Pre-identified Change Factors

Category	Change Reason
A. Business (Owner driven) Scope Change	1.Business Drivers Change (Capacity, reliability, policy)
	2. Budget/Finance Change (Schedule or strategy change)
	3. Plan Change
	4. Scope Error/Omission
	5. Other
B. Standard, Regulatory, and Legal Requirements	6. HSSE Issues
	7. Labor Dispute
	8. Permitting Issues
	9. Other
C. Engineering Design	10. Design/Engineering Errors/Omission
	11. Engineering Productivity
	12. Other
D. Work Planning & Execution	13. Construction Productivity
	14. Construction Errors/Omissions
	15. Construction Equipment Issues
	16. Infrastructure, Site or Utilities Issues
	17. Others
E. Startup Commissioning	18. Startup/Commissioning issues
F. Control System	19. Cost Estimating Issues (People, process, tools, data)
	20. Scheduling Issues (People, process, tools, data)
	21. Cost Forecasting Issues (People, process, tools, data)
	22. Project Management Issues (People, process, data, tools)
	23. Project Team Integration Issues (Data, communications)
	24. Others
G. Vendor/Supplier and Procurement	25. Supplier/Subcontractor Issues
	26. Market Supply Issues
	27. Logistics Issues
	28. Procurement Process Issues (People, process, tools, data)
	29. Others
H. Economic Conditions	30. Foreign exchange
	31. Escalation/Inflation issues
	32. Others
I. Legal & Social Conditions	33. Changes in law (Include taxes, duties)
	34. War/riots/crime/terrorism
	35. Others
J. Natural Threat	36. Acts of God: flood/earthquake/hurricane

The respondents scored the perception of influence for each change reason associated to each submitted project. A scale of increasing impact from 1 to 10 was the base for scoring each change reason, associated to an incremental or deviation forecast from the baseline. Next, this study reported the average impact of the change factor as the average score of the factor x cost and schedule aggregate deviation. This impact depicted the effect of the change reason on cost and schedule performance of projects. Equation 4.10 shows the components of the impact for each change reason.

$$\text{Impact } = \text{Score (level of influence perception) x Aggregate Deviation} \qquad (4.10)$$

Data Screening

Once the information was collected, the data were tabulated and the predictability indices were computed. The information was organized using *Microsoft*© *Excel*© version 2010 and *IBM*© *SPSS*© version 19. A review of missing and suspicious data was undertaken, and then an analysis of normality and outlier was carried out. The variables showed to be non-normal and the different options to transform them were not of practical use. These steps are explained as follows.

Missing and Suspicious Data

Once the data were collected, an initial screening procedure identified those cases with simultaneous zero values in both cost timeliness and aggregate cost deviation. Thus, as commented earlier, from the initial sample of 147 projects, the resulting sample was of 135 projects. Next, an analysis of missing data identified that 5.9% of the 135 projects, 4 projects of contractors and 4 projects of owners, missed quantitative information concerning the schedule forecasts. For these cases, estimation by the technique of expectation-maximization (EM) with an *SPSS*© version 12 program resolved this issue of missed data.

Normality and Outliers

Additionally, an analysis identified the normalized scores of the cost aggregate deviation greater than 2.91, which represented 0.5% of the possible cases. For these cases, estimation by the technique of expectation-maximization (EM) with an *SPSS*© version 12 program resolved this issue of extreme outliers. The variables involved with the predictability index showed a ratio of skewness to its standard error between 6.2 and 12.5 and a ratio of kurtosis to its standard error between 2.7 and 16.4, which indicated significant skewness and kurtosis and non-normality conditions. In consequence, the study utilized non-parametric techniques. To test the hypothesis, the study utilized logistic regression and categorical statistical techniques, where the assumption of normality is not strictly required. Table 3 shows the basic statistics of the final sample.

Table 3

Basic Statistics of the Predictability Index Components

Statistic	P	CPI	CT	CAD	SPI	ST	SAD
N	135	135	135	135	135	135	135
Mean	0.05	0.03	0.07	0.21	0.03	0.08	0.16
SE Mean	0.007	0.004	0.007	0.020	0.004	0.008	0.015
SD	0.076	0.051	0.078	0.227	0.044	0.089	0.169
Skewness	1.94	2.48	1.63	1.85	2.62	1.33	1.30
SE Skewness	0.209	0.209	0.209	0.209	0.209	0.209	0.209
Kurtosis	3.45	5.26	2.05	2.86	6.79	1.11	1.12
SE Kurtosis	0.414	0.414	0.414	0.414	0.414	0.414	0.414

Validity, Reliability, and Generalizability

To guarantee the validity of the measurement instrument that this study used the panel of 20 experts to design and validate the instruments. A thorough literature review aided in identifying past research to clarify and define the main concepts and terms upon predictability.

Next, a pilot test clarified any ambiguous question that had resulted from the former validation process. The quantitative section of the questionnaire measured and collected information about the forecast deviations, hence, there was no problem regarding reliability of the forecasts. Finally, to provide generalizability from this study, the sample warranted a broad composition of the main characteristics of construction projects. There was also wide representation among industry sectors and appropriate diversity in project scale. Table 4 shows the composition of the sample of this study.

Table 4

Sample Demographic Composition

Characteristic	Category	%	Characteristic	Category	%
Year of completion	2010 to Date	65%	Delivery payment method	Lump sum	53%
	2005 to 2009	35%		Cost reimbursable	35%
				Other	11%
Final duration at completion (weeks)	< 40	12%	Final cost at completion ($MM)	<$10	28%
	40 -80	30%		$10 - $50	26%
	80-120	17%		$50 - $110	10%
	120-160	17%		$110 -$500	21%
	>160	24%		>$500	15%
Delivery method	DBB	40%	Industry	Power	17%
	EPC	33%		Petroleum	30%
	Fast track	10%		Heavy industrial	9%
	Turnkey	23%		Chemical	25%
	Other	23%		Other	34%

CHAPTER 5

PREDICTABILITY INDEX

This chapter explains the statistical analysis undertaken to test the predictability indices. First, the chapter statistically describes the characteristics of the variables involved in the predictability indices. Next, the chapter shows the use of logistic regression models to test the predictability indices. Finally, the chapter illustrates a practical application of those significant variables through an analysis of probability.

Descriptive Analysis

In order to know the characteristics of the variables involved in the predictability indices, Table 5 shows the basic statistics of these variables, which will be used in the logistic regression models to test the indices. These variables were calculated with Equations 4.1 to 4.10, formulated in the previous chapter.

Table 5

Basic Statistics of the Predictability Predictors

Statistic	P	CPI	CT	CAD	SPI	ST	SAD
N	135	135	135	135	135	135	135
Median	0.02	0.01	0.04	0.14	0.01	0.06	0.10
Mean	0.05	0.03	0.07	0.21	0.03	0.08	0.16
SD	0.076	0.051	0.078	0.227	0.044	0.089	0.169
First Quartile	0.005	0.001	0.017	0.050	0.0003	0.014	0.019
Second Quartile	0.018	0.005	0.044	0.140	0.006	0.058	0.103
Third Quartile	0.059	0.024	0.103	0.258	0.030	0.120	0.235

Hypothesis Testing

Based on the variables described in the section above, this study assessed the practical use of the predictability indices in relation to small deviations in project cost and schedule at project completion. To assess the predictability index, logistic regression models were used as statistical technique.

Logistic regression is a nonparametric test that allowed predicting the probability of reaching small, aggregated deviations based on predictability indicators (Agresti, 2007). For this purpose, a binary codification of the variables CAD and SAD defined the threshold of admissibility for this study. This codification was based on the greater value of the first quartile between CAD and SAD (see Table 5). Thus, the binary logistic regression models depicted the probability of reaching both cost and schedule aggregate deviations at completion between -5 and +5%.

To show the representativeness and significance of the adopted criterion of small deviations, the study evaluated the aggregate deviations (CAD and SAD) of the sample. This process was conducted to know if the aggregate deviations differed from zero and represented an acceptable set of deviations possible. At the end, the variables CAD and SAD resulted in a representative set of statistical significant deviations, which were differed from 0 and included positive and negative deviations. A nonparametric Wilcoxon matched-pairs signed-rank test showed that CAD were statistically and significantly different from zero at $\alpha = 0.05$ ($T = -4.147$, $df = 135$, $p < 0.001$), with positive deviation ranks $(\sum \mathrm{R}_{+}) = 6{,}478$ and negative deviation ranks $(\sum \mathrm{R}_{-}) = 2{,}702$. Likewise, the schedule aggregate deviations (SAD) were statistically and significantly different from zero at $\alpha = 0.05$ ($T = -7.272$, $df = 127$, $p < 0.001$), with positive deviation ranks ($\sum R_+$) $= 4{,}558$ and negative deviation ranks ($\sum R_-$) $= 392$. Table 6 shows a summary of the test.

Table 6

Wilcoxon Matched-pairs Signed-rank Test

Variable	T statistics	df	P	$\sum R_+$	$\sum R_-$
CAD	-4.147	135	< .01	6,748	2,702
SAD	-7.272	127	< .01	4,558	392

Additionally, in order to validate the logistic regression models, this study built the models with a random sample of 94 cases drawn from the initial sample size of 135 projects and the remaining 41 cases validated the results. Thus, this study considered three possible models of interest. The first model involved the variable predictability (P), as calculated with Equation 4.1. The second model involved the variable cost timeliness (CT), as calculated with Equation 4.3. Finally, the third model involved the variable schedule timeliness (ST), as calculated with Equation 4.6.

The first model included the variable P as predictor, and as response, a binary variable that depicted the deviations of cost and schedule at completion less than 5%. Based on this model, P resulted being a significant predictor. The Hosmer and Lemeshow test resulted in a non-significant $\chi^2 = 0.960$, df = 8, and p = 0.998, which indicated a good fit of the model with 95% of prediction effectiveness. The effect size indicated that the model explains substantially the probability to achieve good deviation performance (Cox & Snell $R^2 = 0.382$; Nagelkerke $R^2 = 0.776$). The model coefficients were statistically significant at $\alpha = 0.05$: B_0 (Constant) = 2.420, Wald = 5.209, df = 1, p = 0.001; and B_1 (P) = -1,408.079, Wald = 7.124, df = 1, p = 0.008. Equation 5.1 shows the final model of the binary logistic regression and Appendix C shows the

SPSS© outputs of the regression model. In short, there is statistical evidence to say early and accurate predictions of cost and schedule performance add significant value. Projects with predictability values close to zero, early and accurate predictions, showed more likely to reach small cost and schedule deviations of less than 5%. Table 7 shows a summary of the test.

$$\Pi\ (\text{Cost \&Schedule Deviations } \leq 5\%) = \frac{1}{1 + e^{-[2.420\ -1408.079\text{P}]}} \tag{5.1}$$

A second model included as predictor the variable Cost Timeliness (CT), and as response, a binary variable that depicted the deviations of cost at completion less than 5%. Based on this model, CT resulted in being a significant predictor, which becomes a predictability index (CPI) significantly indicative of achieving admissible cost deviations. The Hosmer and Lemeshow test resulted in a non-significant $\chi^2 = 2.116$, df = 8, and p = 0.977, which indicated a good fit of the model with 85% prediction effectiveness. The effect size indicated that the model substantially explains the probability to achieve good deviation performance (Cox & Snell $R^2 = 0.450$; Nagelkerke $R^2 = 0.670$). The model coefficients were statistically significant at $\alpha = 0.05$: B_0 (Constant) = 2.382, Wald = 11.143, df = 1, p = 0.001 and B_1 (CT) = -130.977, Wald = 15.177, df = 1, p < 0.001). Equation 5.2 shows the final model of the binary logistic regression and Appendix C shows the *SPSS*© outputs of the regression model. In short, there is statistical evidence that timeliness is a significant component of the predictability index. Projects with cost timeliness values close to zero, early and accurate predictions, were more likely to reach small cost deviations of less than 5%. Table 7 shows a summary of the test.

$$\Pi\ (\text{Cost Deviation} \leq 5\%) = \frac{1}{1 + e^{-[2.382\ -130.977\text{CT}]}} \tag{5.2}$$

Complementarily, a third model included as predictor the variable Schedule Timeliness (ST), and as response, a binary variable that depicted the deviation of schedule at completion less than 5%. Although schedule timeliness resulted being a non-significant predictor, this study could not be conclusive because the model met other statistical criteria. The Hosmer and Lemeshow test resulted in a non-significant $\chi^2 = 46.984$, df = 8, and $p < 0.001$, which indicated that there is no statistical evidence to support the model. Nevertheless, the model showed over 85% prediction effectiveness and the effect size indicated a substantial explanation of the probability to achieve good deviation performance (Cox & Snell $R^2 = 0.446$; Nagelkerke $R^2 = 0.644$). Therefore, the study was non-conclusive based on the significance of the model but suggested the practical usability of it. The coefficients were statistically significant at $\alpha = 0.05$: B_0 (Constant) = 1.732, Wald = 10.204, df = 1, p = 0.001 and B_1 (ST) = -59.489, Wald = 18.356, df = 1, p < 0.001). Equation 5.3 shows the final model of the binary logistic regression and Appendix C shows the *SPSS*© outputs of the regression model. In short, there is evidence to say that projects with schedule timeliness values close to zero, early and accurate predictions, were more likely to reach small schedule deviations of less than 5%. Table 7 shows a summary of the test.

$$\Pi\ (\text{Schedule Deviation} \leq 5\%) = \frac{1}{1 + e^{-[1.732\ - 59.489\text{ST}]}} \qquad (5.3)$$

Table 7

Logistic Regression Models Test Summary

Statistics		Model 1	Model 2	Model 3
Hosmer& Lemeshow test	χ^2	.96	2.116	46.984
	Df	8	8	8
	P	.99	.98	< .01
Nagelkerke	R^2	.78	.67	0.64

Table 7 (con't.)

Statistics		Model 1	Model 2	Model 3
B_0	b_0	2.42	2.38	.732
	Wald	5.209	11.143	10.204
	Df	1	1	1
	P	< .01	< .01	< .01
B_1	b_1	-1,404.08	-130.98	-59.49
	Wald	7.124	15.177	18.356
	Df	1	1	1
	P	< .01	< .01	< .01

Probability Analysis

Since the logistic regression models resulted in significant predictors, the following probabilistic analysis identified the thresholds of predictability, cost timeliness, and schedule timelines, with respect to achieving cost and schedule aggregate deviations at completion less than 5%. Based on the first logistic regression model of Equation 5.1, which yielded an effectiveness of over 95%, when a project showed a predictability (P) = 0.0017, there was a 50% probability of achieving deviations of less than 5%, evaluated at completion. The probability increased when the predictability (P) of the project was less than 0.0017 (see Figure 7). The respective odds ratio indicated that as the predictability of the project increased 0.0001 units, the probability to achieve the admissible deviation decreased 0.87 times, with 95% of confidence, the deviation decreased between 0.78 and 0.96. On the contrary, as the predictability of the project decreased by .0001 units, the probability to achieve the admissible deviation increased 1.15 times (15%), with 95% of confidence, the deviation increased between 1.04 and 1.28. Thus, there was further evidence to explain the better performance of projects that held low predictability values, less than 0.0017 and near to zero.

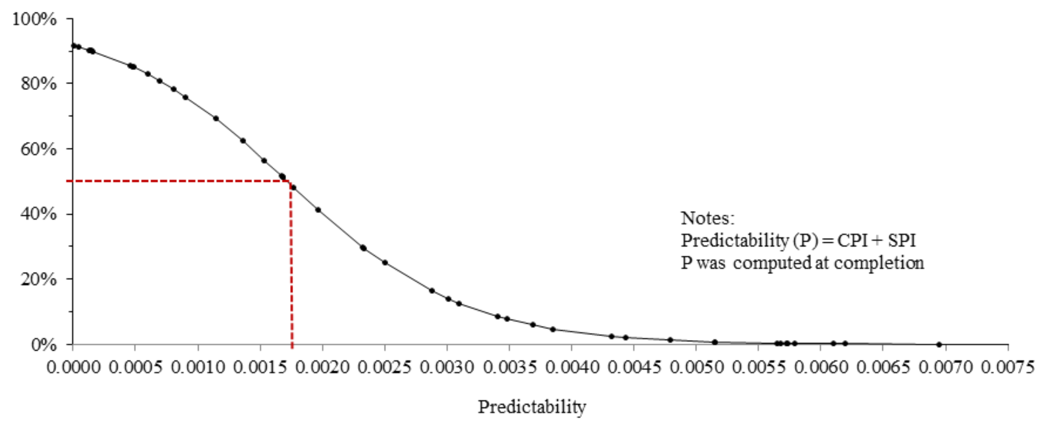

Figure 7. Probabilities of Deviations Less than 5% by Predictability.

Likewise, based on the second logistic regression model of Equation 5.2, which held 85% effectiveness, when cost timeliness equaled to 0.018, there was 50% probability to achieve, at completion, a cost aggregate deviation less than 5%. The probability of the project increased when CT was less than 0.018 (see Figure 8). The respective odds ratio indicated that as CT increased by 0.001 units, the probability to achieve the admissible deviation decreased 0.88 times, with 95% of confidence, the deviation decreased between 0.82 and 0.94. On the contrary, as CT decreased by 0.001 units, the probability to achieve the admissible deviation increased 1.14 times (14%), with 95% of confidence, the deviation increased between 1.06 and 1.22.

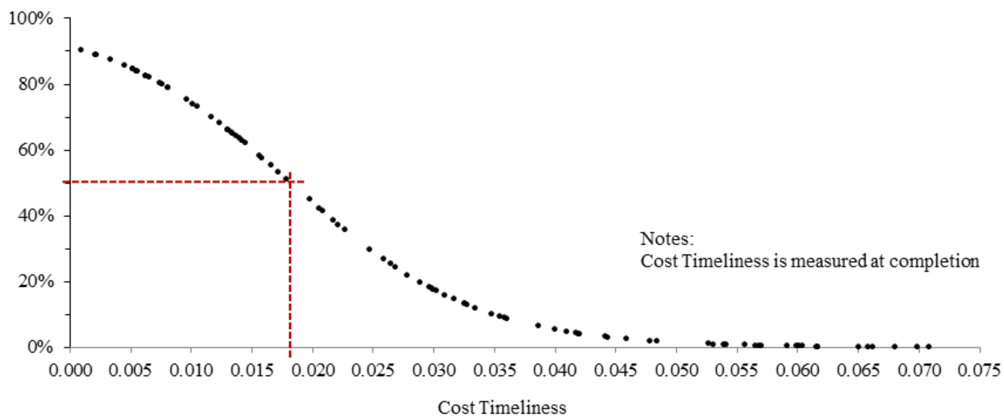

Figure 8. Probabilities of admissible cost deviation by timeliness.

Finally, based on the second logistic regression model of Equation 5.3, with over 85% of effectiveness, when schedule timeliness was 0.029 there was a 50% probability at completion with a schedule aggregate deviation of less than 5%. The probability increased when ST was less than 0.029 (see Figure 9). The respective odds ratio indicated that as ST increased by 0.001 units, the probability to achieve the admissible deviation decreased 0.94 times, with 95% of confidence, the deviation decreased between 0.92 and 0.97. On the contrary, as ST decreased 0.001 units, the probability to achieve the admissible deviation increased 1.06 (6%) times, with 95% of confidence, the deviation decreased between 1.04 and 1.09.

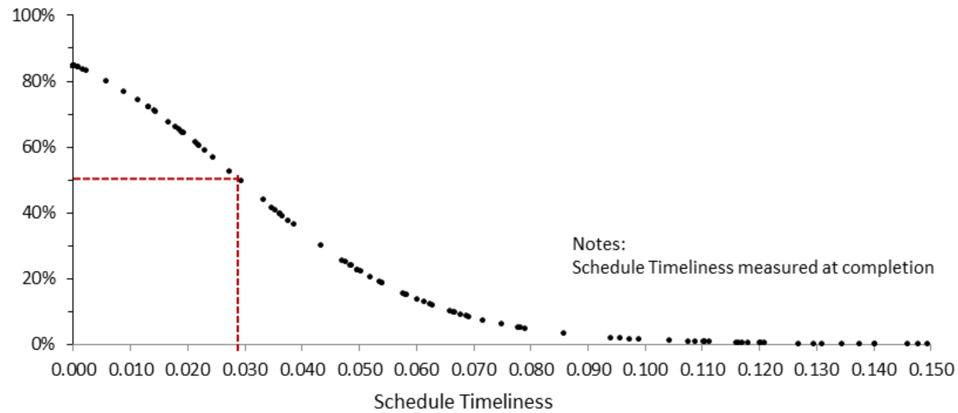

Figure 9. Probabilities of admissible schedule deviation by timeliness.

On the other hand, the study focused on segregated blocks of the data set, defined by the quartiles (0.25 of the distribution) of the variable predictability (P). In ascending order, the first quartile (Q1) determined those projects with a good level of predictability (early and accurate predictions). Analogously, the fourth quartile (Q4), determined the projects with poor levels of predictability (untimely and inaccurate). Table 8 shows the basic statistics of the predictability data segregated by quartiles Q1 and Q4, the best and worst scenarios of predictability. Appendix C shows a detailed description of the basic statistics for each variable segregated by Q1 and Q4. The following analysis describes the best and worst scenarios. With 95% confidence, the mean predictability of Q1 was between 0.001 and 0.002 and the mean predictability of Q4 was between 0.134 and 0.178. Q1 projects showed predictability values with less dispersion than those of Q4.

Table 8

Basic Statistics Segregate by Q1 and Q4

Variable	Group	N	Median	Mean
Predictability (P)	1st Quarter (Predictability <= .005)	34	0.0017	0.0018
	4th Quarter (Predictability >= .059)	34	0.1815	0.1562
Cost Predictability Index (CPI)	1st Quarter (Predictability <= .005)	34	0.0007	0.0011
	4th Quarter (Predictability >= .059)	34	0.0640	0.0874
Cost Timeliness (CT)	1st Quarter (Predictability <= .005)	34	0.0136	0.0174
	4th Quarter (Predictability >= .059)	34	0.1539	0.1602
Cost Aggregate Deviation (CAD)	1st Quarter (Predictability <= .005)	34	0.0476	0.0493
	4th Quarter (Predictability >= .059)	34	0.4378	0.4629
Schedule Predictability Index (SPI)	1st Quarter (Predictability <= .005)	34	0.0000	0.0007
	4th Quarter (Predictability >= .059)	34	0.0567	0.0755
Schedule Timeliness (ST)	1st Quarter (Predictability <= .005)	34	0.0008	0.0165
	4th Quarter (Predictability >= .059)	34	0.1798	0.1747
Schedule Aggregate Deviation (SAD)	1st Quarter (Predictability <= .005)	34	0.0044	0.0208
	4th Quarter (Predictability >= .059)	34	0.3622	0.3506

Regarding CT with 95% confidence, the mean CT of Q1 was between 0.013 and 0.021, and the mean CT of Q4 was between 0.13 and 0.19, which indicates that Q1 was more efficient than Q4 with a ratio of 1:9. Likewise, with 95% confidence, the mean ST of Q1 was between 0.009 and 0.024, and the mean ST of Q4 was between 0.142 and 0.207. This finding demonstrates that with a ratio of 1:10, Q1 showed better efficiency than Q4. Figure 10 shows the segregated quartiles of predictability performance based on timeliness for cost and schedule.

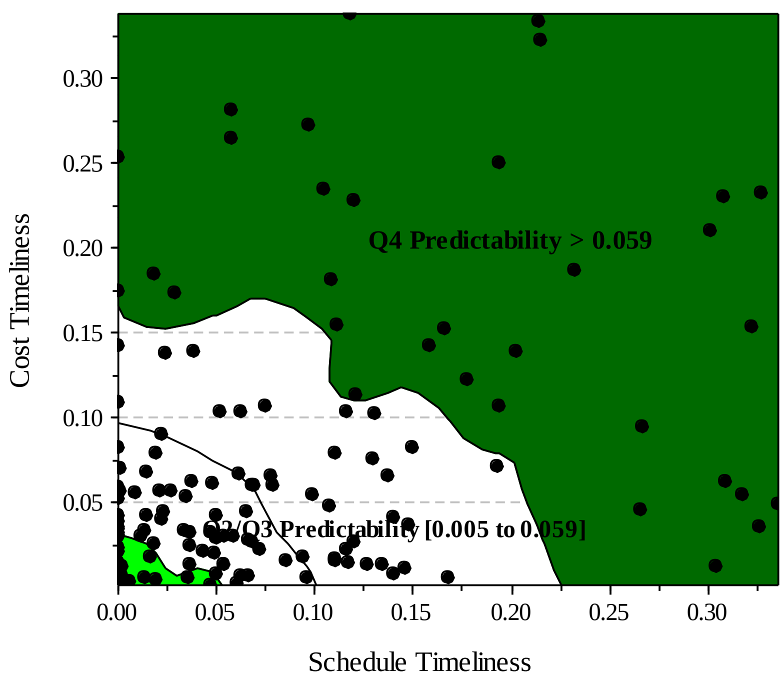

Figure 10. Segregated quartiles of predictability by timeliness.

Regarding aggregate deviations, the results showed with 95% confidence that the mean CAD of Q1 was between 0.038 and 0.060, and the mean CAD of Q4 was between 0.360 and 0.566. It meant that the effectiveness in ensuring the project final cost of Q1 was better than that of Q4 with a ratio of 1:9. Likewise, with 95% confidence, the mean SAD of Q1 was between 0.012 and 0.030, and the mean SAD of Q4 was between 0.285 and 0.409. This finding indicates that ensuring the final duration, the group Q1 was more effective than Q4, with a ratio of 1:16. Figure 11 shows the quartiles of predictability performance based on the aggregate deviations.

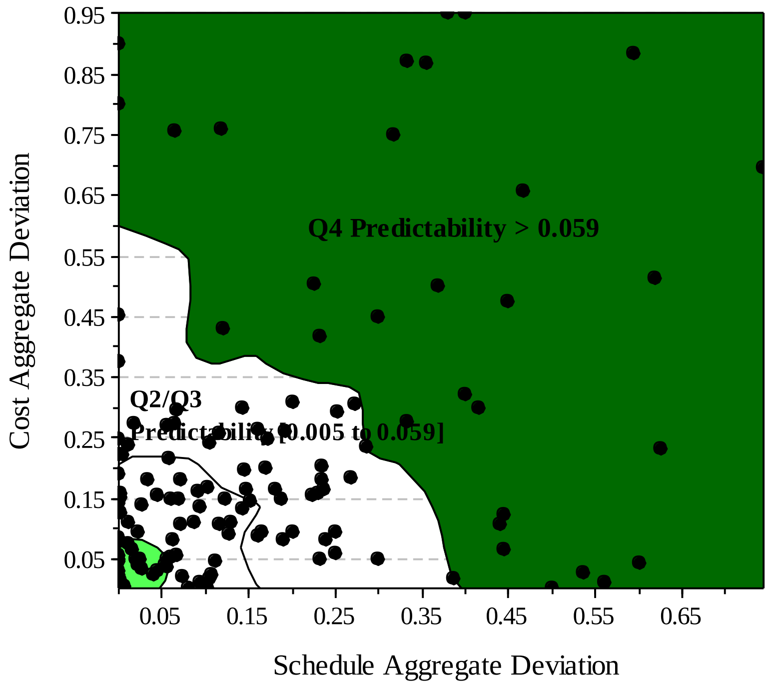

Figure 11. Segregated quartiles of predictability by deviations.

Findings from this study have shown statistical evidence of the relationship between the predictability indices with the achievement of small deviations of project cost and schedule. In addition, the study has illustrated a practical application of those significant variables through an analysis of probability. To achieve aggregate cost and schedule deviations at completion, with less than 5% and with a probability of 50%, cost predictability index plus schedule predictability index must be less than 0.0017. As this predictability index decreases, the probability of reaching admissible deviations increases. If the projects show cost timeliness and schedule timeliness, computed at completion, less than 0.018 and less than 0.29 respectively, there is 50% probability of achieving aggregate deviations at completion, with less than 5%. As these indices decrease, the probability of reaching the admissible deviations increases.

CHAPTER 6

CHANGE REASONS

This chapter explains the statistical analysis undertaken for the significant change reasons. First, the characteristics of the variables involved are described in regard to their relationships between change reasons and the predictability index. Next, the chapter shows the testing of hypotheses. Finally, the chapter shows an analysis of probability of the significant change reasons influencing the predictability index.

Descriptive Statistics

The Table 9 below shows the roster of 36 pre-identified change reasons associated with predictability and summarizes the average score, the average impact, and the frequency for each change reason. The score is the average perception of influence of a change reason that was rated on a 10-point scale by the management team in charge of the respective submitted project. The impact of any change reason was the average of score times the aggregate deviation, regarding the projects associated to such specific change reason. Finally, the frequency is the percentage of projects associated to a specific change reason.

Table 9

Pre-identified Change Reasons and Frequencies

CATEGORY	CHANGE REASON	Average Score	Average Impact	Frequency
A. Business (Owner driven) Scope Change	1. Business Drivers Change	7.43	2.68	19%
	2. Budget/Finance Change	6.64	1.90	23%
	3. Plan Change	7.43	2.74	43%
	4. Scope Error/Omission	7.49	2.66	33%
	5. Other	6.71	1.86	16%
B. Standard, Regulatory, and Legal Requirements	6. HSSE Issues	6.73	1.53	10%
	7. Labor Dispute	8.25	3.05	1%
	8. Permitting Issues	6.47	1.83	7%
	9. Other	5.50	2.61	5%
C. Engineering Design	10. Design/Engineering Errors/Omission	6.01	1.38	44%
	11. Engineering Productivity	5.77	1.56	26%
	12. Other	4.00	1.13	6%
D. Work Planning & Execution	13. Construction Productivity	6.95	1.63	49%
	14. Construction Errors/Omissions	5.83	0.98	10%
	15. Construction Equipment Issues	5.79	2.92	14%
	16. Infrastructure, Site or Utilities Issues	7.13	2.35	13%
	17. Others	7.76	1.88	12%
E. Startup	18. Startup/Commissioning issues	6.50	1.15	26%
F. Control System	19. Cost Estimating Issues	5.14	1.47	23%
	20. Scheduling Issues	6.07	1.93	16%
	21. Cost Forecasting Issues	4.32	1.31	8%
	22. Project Management Issues	6.19	2.57	10%
	23. Project Team Integration Issues	7.43	2.79	7%
	24. Others	6.00	2.42	4%
G. Vendor/Supplier and Procurement	25. Supplier/Subcontractor Issues	5.90	1.24	33%
	26. Market Supply Issues	4.38	0.79	10%
	27. Logistics Issues	6.01	2.41	10%
	28. Procurement Process Issues	5.41	2.47	12%
	29. Others	3.65	0.92	5%
H. Economic Conditions	30. Foreign exchange	3.86	2.08	5%
	31. Escalation/Inflation issues	2.67	0.54	7%
	32. Others	5.00	3.41	1%
I. Legal & Social Conditions	33. Changes in law	3.00	0.87	1%
	34. War/riots/crime/terrorism	0.00	0.00	0%
	35. Others	4.00	1.17	1%
J. Natural Threat	36. Acts of God: flood/earthquake/hurricane	4.94	1.74	10%

Note: N=135 projects

Hypothesis Testing

This study tested the relationship between some pre-identified change reasons and the index of predictability of the projects. To test this hypothesis, a bivariate analysis with predictability (P) as the dependent variable identified the change reasons with significant and important level of association. At the significance level $\alpha = 0.05$, this study used a Kendall's tau-b coefficient, a nonparametric measure of correlation for ranked and non-normal data (Agresti, 2010). For the level of association, this study utilized effect sizes given by De Vaus (2001). A coefficient between 0.90 and 0.99 indicated a near perfect relationship; a coefficient between 0.70 and 0.89, a very strong relationship; a coefficient between 0.50 and 0.69, a substantial relationship; a coefficient between 0.30 and 0.49, a moderate relationship; a coefficient between 0.10 and 0.29, a low relationship; and finally a coefficient between 0.01 and 0.09, a trivial relationship. Table 10 shows 26 significant change reasons associated with predictability and the respective effect size. Once the relevant change reasons were identified, a multicollinearity analysis was conducted to check those reasons that were strongly correlated with each other. This was done in order to suggest aggregate reasons rather than individual ones and to identify possible redundant measures. Appendix C shows the *SPSS*© outcomes of the correlation analysis.

Table 10

Significant Change Reasons Related to Predictability

Significant Change Reason	Kendall's Tau_b coefficient (τ)	N	Effect Size
H.30 Foreign exchange	0.810	7	Very strong
D.15 Construction Equipment Issues	0.754	19	Strong
F.20 Scheduling Issues	0.714	21	Strong
A.4 Scope Error/Omission	0.711	45	Strong
B.6 HSSE Issues	0.710	13	Strong

Table 10 (con't.)

Significant Change Reason	Kendall's Tau_b coefficient (τ)	N	Effect Size
C.11 Engineering Productivity	0.665	35	Substantial
B.8 Permitting Issues	0.657	7	Substantial
D.16 Infrastructure, Site or Utilities Issues	0.657	17	Substantial
F.23 Project Team Integration Issues	0.648	9	Substantial
F.21 Cost Forecasting Issues	0.636	11	Substantial
A.3 Plan Change	0.614	58	Substantial
J.36 Acts of God	0.584	13	Substantial
G.25 Supplier/Subcontractor Issues	0.562	45	Substantial
D.14 Construction Errors/Omissions	0.560	14	Substantial
F.22 Project Management Issues	0.560	14	Substantial
G.27 Logistics Issues	0.560	14	Substantial
C.10 Design/Engineering Errors/Omission	0.543	60	Substantial
D.13 Construction Productivity	0.541	66	Substantial
E.18 Startup/Commissioning issues	0.533	35	Substantial
F.19 Cost Estimating Issues	0.528	31	Substantial
A.1 Business Drivers Change	0.522	26	Substantial
D.17 Work Planning & Execution -Others	0.517	16	Substantial
G.26 Market Supply Issues	0.489	14	Moderate
A.2 Budget/Finance Change	0.487	31	Moderate
A.5 Business Owner driven–Other	0.474	22	Moderate
G.28 Procurement Process Issues	0.417	16	Moderate

Note: from the 36 initial pre-identified change reason, 26 resulted significant at α=0.05.

As a result from the test of hypothesis, 26 change reasons were statistically significant and the following reasons showed evidence of multicollinearity: (A.2) Budget/Finance Change, (A.3) Plan Change and (A.4) Scope Error/Omission, which indicated that these three reasons might mean the same.

Probability Analysis

Due to different contractual interests between owners and contractors, the following analysis takes into account this fact joined the concept of relative risk (RR) of an event (see Agresti, 2007 and Scheaffer, 1995). RR is a ratio of event probabilities which guided the probability analysis of the significant 26 reasons. For this study, RR is the occurrence of a specific change reason that negatively affects the predictability performance, estimated with a two-by-two contingency table of predictability by change-reason. In consequence, both groups of predictability, projects with predictability > .004788 (> Q1) and projects with predictability ≤ .004788 (Q1), and the occurrence of the change reasons associated with each group, were the basis for computing RR. Thus, RR is the ratio of the odds of a change reason, which indicates the probability of having an adverse impact when the change reason occurs at the group of predictability >Q1 divided by the probability of having an adverse impact when the change reason occurs at the group Q1. Table 11 illustrates the analysis undertook for the change reason A1 (Business Drivers Change).

Table 11

Contingency Table Predictability by Change Reason (A1)

		Occurrence A1		
Role	Group of Predictability	YES	NO	Total
CONTRACTOR	Predictability > .004788	8	40	48
	(>Q1)	17%	83%	100%
	Predictability <= .004788	2	20	22
	(Q1)	9%	91%	100%
OWNER	Predictability > .004788	11	42	53
	(>Q1)	21%	79%	100%
	Predictability <= .004788	5	7	12
	(Q1)	42%	58%	100%

Thus, for a contractor, the odds of A1 having an adverse impact when it occurs at group >Q1 is 0.20 (17% divided by 83%). The odds of A1 having an adverse impact when it occurs at group Q1is 0.10 (9% divided by 90%). The RR for a contractor of having a project with predictability > Q1, affected by A1, is 2.00 (0.20 divided by 0.10); which means that for contractors, (A1) Business Drivers Change is 2.00 times more likely to produce cost and schedule deviations greater than 5%. Recalling the analysis of the predictability indexes, those projects with predictability > Q1 showed deviations greater than 5% in cost and schedule (see

Figure 11). Additionally, the study quantified the effect of risk multiplying RR by the respective impact. Table 12 below shows the 26 significant change reasons with their RR, the average impact associated to cost deviations, and the risk effect, differentiated by contractors and owners. Appendix C shows the *SPSS*© outputs of the frequencies for each change reason.

Table 12

Risk of Occurrence—Predictability by Change Reason

Significant Change Reason	OWNER			CONTRACTOR		
	RR (>Q1/Q1)	Average Impact	Risk Effect	RR (>Q1/Q1)	Average Impact	Risk Effect
A.1 Business Drivers Change	0.37	1.73	0.63	2.00	6.01	12.02
A.2 Budget/Finance Change	1.15	0.76	0.87	0.41	3.67	1.51
A.3 Plan Change	1.67	1.98	3.32	1.86	4.37	8.12
A.4 Scope Error/Omission	1.07	3.56	3.82	1.67	2.72	4.55
A.5 Business Owner driven –Other	0.63	2.08	1.32	0.25	3.84	0.96
B.6 HSSE Issues	0.61	2.06	1.27	0.45	0.38	0.17
B.8 Permitting Issues	0.09	0.01	0.01	0.58	3.82	2.20
C.10 Design/Engineering Errors/Omission	0.19	1.79	0.35	3.21	1.59	5.10
C.11 Engineering Productivity	0.46	1.72	0.78	0.79	2.59	2.05
D.13 Construction Productivity	1.21	2.05	2.48	0.93	2.00	1.87
D.14 Construction Errors/Omissions	1.67	1.42	2.37	0.42	1.08	0.46
D.15 Construction Equipment Issues	3.58	3.77	13.48	1.90	1.56	2.97
D.16 Infrastructure, Site or Utilities Issues	2.88	2.74	7.88	2.44	1.79	4.37
D.17 Work Planning & Execution –Others	1.67	2.85	4.77	3.59	1.40	5.01
E.18 Startup/Commissioning issues	1.46	1.35	1.98	0.19	1.96	0.38
F.19 Cost Estimating Issues	2.25	2.29	5.14	1.70	1.48	2.52
F.20 Scheduling Issues	2.56	2.39	6.10	5.53	1.67	9.23
F.21 Cost Forecasting Issues	0.66	1.54	1.01	3.59	1.34	4.81
F.22 Project Management Issues	2.25	3.15	7.10	1.40	2.45	3.43
F.23 Project Team Integration Issues	0.66	4.55	3.00	2.44	2.29	5.60
G.25 Supplier/Subcontractor Issues	0.65	1.80	1.17	0.55	1.57	0.86
G.26 Market Supply Issues	0.24	1.26	0.31	3.59	0.73	2.62
G.27 Logistics Issues	2.88	2.88	8.28	0.45	1.81	0.81
G.28 Procurement Process Issues	1.67	3.56	5.95	4.2	1.83	7.70
H.30 Foreign exchange	0.66	2.61	1.72	1.91	1.68	3.21
J.36 Acts of God	0.20	0.34	0.07	4.2	2.69	11.30

Note: Significant at α=.05

Based on the results shown in Table 12, a prioritization, based on the risk effect of the change reasons and segregate by owners and contractors, identified three levels of priority that impacted adversely on cost and schedule deviations.

The low-risk level grouped those change reasons with odds ratios less than or equal to 2.0, in other words, change reasons with low probability of occurrence at >Q1 group. The medium-risk level grouped those change reasons with odds ratios between 2.0 and 6.0. Finally, the high-risk level grouped the change reasons with odds ratio greater than 6.0. Among the high-risk level, for owners the change reasons with major effect were D.15—Construction Equipment Issues, D.16—Site Issues, F.20—Scheduling Issues, F.22—Project Management Issues, G.27—Logistics Issues, and G.28—Procurement Process Issues; while contractors identified as change reasons of major effect A.1—Business Drivers Change, A.3—Plan Change, F.20—Scheduling Issues, G.28—Procurement Process Issues, and J.36—Acts of God. The medium-risk level showed that while owners identified A.3—Plan Change, A.4—Scope Error/Omission, D.13—Construction Productivity, D.14—Construction Error/Omission, D.17—Work-Planning Execution, F.19 Cost Estimating Issues, and F.23—Project Team Integration Issues; while contractors identified A.4—Scope Error/Omission, B.8—Permitting Issues, C.10—Design/Engineering Errors/Omission D.15—Construction Equipment Issues, D.16—Infrastructure, Site, or Utilities Issues, D.17—Work-Planning Execution, F.19—Cost Estimating Issues, F21—Cost Forecasting Issues, F.22—Project Management Issues, F.23—Project Team Integration Issues, G.26—Market Supply Issues, and H.30—Foreign Exchange. The remaining significant change reasons were classified as low-risk level (see Figure 12).

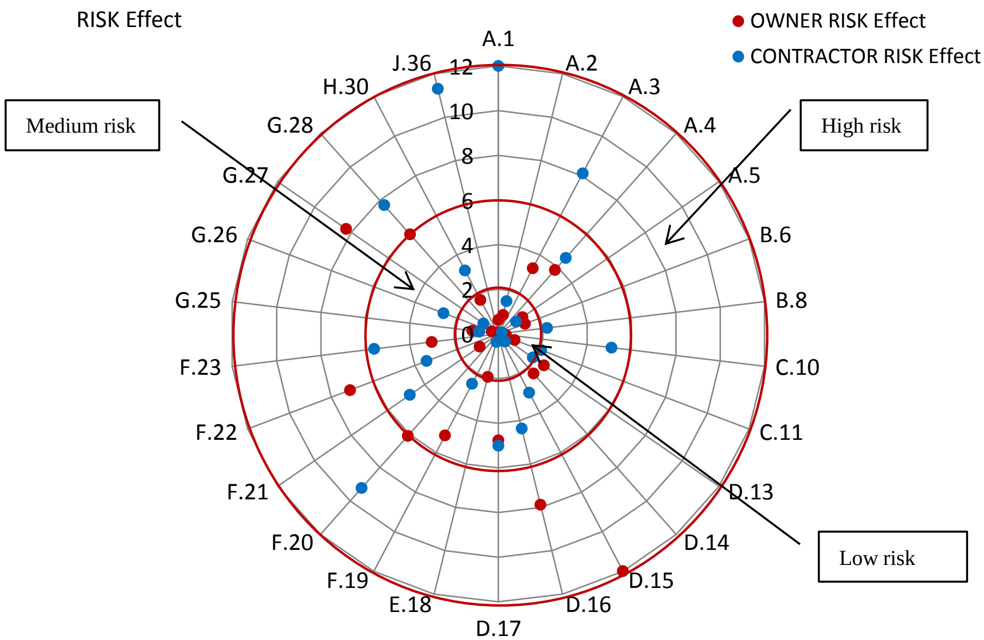

Figure 12. Map of priority of probability of impact.

CHAPTER 7

UNDERLYING FACTORS

This chapter shows the results of this research concerning the factors that influenced predictability. First, a section about descriptive statistics shows the frequencies of the factors analyzed in the study. Next, a hypothesis testing section describes those factors that were statistically significant. Finally, a probability analysis section explains the most relevant factors from those significant ones, based on a frequency analysis.

Descriptive Statistics

Over 60 pre-identified factors described the most common characteristics and conditions in the context of forecasting in construction. Four major categories (i.e., project characteristics, forecasting practices, management practices, and human factors) grouped these characteristics and conditions. The frequencies of these factors are explained by each major category as follows.

Project Characteristics

This major category grouped 17 factors that described the main characteristics and physical conditions of constructions projects. The first factor described the sample of projects based on the relationship between project and source of information: owner-projects and contractor-projects. Thus, the sample was made up of 65 projects (48%) associated with owners and 70 projects (52%) associated with contractors. The remaining 16 factors are shown in Table 13. Almost all factors showed a fairly even distribution through their subcategories, except one factor that revealed information about the familiarity of the company within the region where the project was executed (Q1.5). This fairly even distribution of the factors and subcategories suggests a consistent hypothesis testing. To know the survey questions related to each factor, see Appendix A.

Table 13

Frequency Distribution of Project Characteristic Factors

Characteristic	Category	%	Characteristic	Category	%
Affiliation (Q1.2)[a]	Public	49%	Payment Method	Lump sum	53%
	Private	47%	(Q1.16)	Cost reimbursable	35%
	Both	4%		Other	11%
Third Party Funding	Unknown	12%	Project Driver	Cost	18%
(Q1.4)	It self	73%		Schedule	53%
	In part /Some	4%		Both	17%
	Yes	10%		Other	12%
Year of completion	2010 to Date	65%	Region-Familiarity	Yes	6%
(Q1.6)	2000 to 2009	35%	(Q1.5)	No	94%
Technology	No (New)	18%	Site Location	Outside of US	25%
Familiarity (Q1.8)	Yes (Known)	82%	(Q1.3)	Inside of US	75%
Project Nature	Greenfield	17%	Legal Constraints	Many	52%
(Q1.14)	Brownfield	24%	(Q1.15)	Few	14%
	Renovation	59%		None/NA	34%
Final duration at	< 40	12%	Final cost at	<$10	29%
completion (weeks)	40 -80	30%	completion ($MM)	$10 - $50	24%
(Q1.7)	80-120	17%	(Q1.11)	$50 - $110	8%
	120-160	17%		$110 -$500	22%
	>160	24%		>$500	17%
Delivery method	DBB[b]	31%	Industry	Power	15%
(Q1.13)	EPC[c]	26%	(Q1.12)	Petroleum	25%
	Fast track	8%		Heavy industrial	8%
	Turnkey	18%		Chemical	22%
	Other	17%		Other	30%
Incentives	Yes	38%	Office Structure	Central office	25%
(Q1.17)	No	62%	(Q1.10)	Local office	42%
				Mixed	33%

[a] (Q1.2): Question 1.2. See Appendix A
[b] DBB: Design-Bid-Build
[c] EPC: Engineering-Procurement-Construction

Forecasting Practices

Within this major category, 19 factors described the context of forecasting practices in construction projects. Table 14 shows the composition of these 19 factors and Appendix A shows the survey questions related to each factor within the present major category. As in the previous major category, the distribution of the subcategories within each factor was evenly distributed for this major category.

Table 14

Frequency Distribution of Forecasting Practice Factors

Characteristic	Category	%	Characteristic	Category	%
Forecast data source (Q2.2.)[a]	Project Manager	23%	Forecaster (Q2.3) [a]	Project Manager	21%
	Project Controls – Field	16%		Project Controls – Field	26%
	Project Controls – Central Office	20%		Project Controls – Central Office	30%
	Project Team	21%		Project Team	9%
	Construction Manager	15%		Construction Manager	4%
	Other	5%		Other	10%
Forecast validator(Q2.4) [a]	Project Manager	40%	Forecast report to (Q2.5) [a]	Finance	20%
	Project Controls – Field	12%		Engineering	15%
	Project Controls – Central Office	14%		Owner	24%
	Project Team	15%		Company Management	36%
	Construction Manager	11%		Other	1%
	Other	8%		None/NA	4%
Team Skills (Q2.6)	Very skilled	57%	Control Structure (Q2.9) [a]	Project site	34%
	Competent	35%		Central office	62%
	Growing	4%		Other	1%
	No opinion	4%		None	3%
Available Information (Q2.7)	Frequent	75%	Accuracy Assessment (Q2.11)	Yes	35%
	Occasional	21%		No	65%
	Rarely	4%			
Data sources (Q2.8) [a]	Current budget	18%	Forecasting method (Q2.10) [a]	Earned Value system	57%
	Physical reports	18%		Time series	7%
	Procurement log	16%		Combined methods	22%
	Project schedule	18%		Probabilistic	2%
	Change/trend log	16%		Range estimating	8%
	Productivity reports	14%		Other	4%
Deviation Reporting (Q2.13)	<1 month	37%	Forecasting Report (Q2.14)	Weekly	1%
	1 - 3 months	46%		Bi-weekly	3%
	3 - 6 moths	15%		Monthly	77%
	6 - 12 months	1%		Quarterly	17%
	Unknown	1%		Other	2%
Base for Budgeting Contingency (Q2.16)	Quantified risk	14%	Criteria for using Contingency (Q2.17)	Budget stage-risk	5%
	Mixed	66%		Any event-risk	44%
	Remaining cost	20%		Manager judgment	51%
Risk update (Q2.18)	Routinely	33%	Completion date Reported (Q2.20)	Stakeholders' target	9%
	Case basis	43%		Project team' target	58%
	Not at all	24%		The most likely date	33%

Table 14 (con't.)

Characteristic	Category	%	Characteristic	Category	%
Contingency level of revision (Q2.19)	Not at all	3%	Accuracy method (Q2.12)	Final cost deviation	58%
	Macro level	49%		Mean error	2%
	Line/no detail	14%		Probabilistic	19%
	Line/detail	34%		Other	21%
Forecast report for (Q2.5) [a]	Planning	27%			
	Financial reports	19%			
	Management	31%			
	Partners	4%			
	Client/Customer	16%			
	Third party financing	3%			

[a] Multiple selection question

Management Practices

Regarding management practices, Table 15 shows the composition of the 20 factors that described the context of management practices in construction. In addition, Appendix A shows the survey questions related to each factor within this major category. All factors showed a fairly even distribution through their subcategories except the factor that gave information about the integration between control and management (Q3.11). This even distribution of the factors and subcategories suggests a consistent hypothesis testing.

Table 15

Frequency Distribution of Management Practice Factors

Characteristic	Category	%	Characteristic	Category	%
Front-end-planning (FEP) (Q3.1)	Yes	85%	Integration control and management (Q3.11)	Yes	93%
	No	15%		No	7%
Level of FEP (Q3.2)	Low	10%	PDRI[a] (Q3.3)	Yes	14%
	Medium	40%		No	73%
	High	50%		Other tool	13%
Information integration (Q3.7)	Excellent	30%	Databases utilization (Q3.8)	Very satisfactory	15%
	Satisfactory	56%		Satisfactory	30%
	Disappointing	5%		No implementation	25%
	NA	9%		NA	30%
Change request Frequency (Q3.9)	Very frequent	10%	Strategic alliances satisfaction (Q3.10)	Very satisfactory	20%
	Frequent	38%		Satisfactory	37%
	Occasional	42%		Poor	5%
	Rarely	10%		No implementation	20%
				NA	18%

Table 15 (con't.)

Characteristic	Category	%	Characteristic	Category	%
Alignment level (Q3.6)	Complete	59%	RFIs[b] frequency (Q3.14)	Very frequent	5%
	Somewhat	24%		Frequent	50%
	Varied	7%		Occasional	41%
	No alignment	1%		Rarely	3%
	NA	9%		Very rarely	1%
Final cost performance Reported (Q3.12)	< -5%	30%	Final schedule reported (Q3.13)	< -5%	13%
	-5% to 0%	20%		-5% to 0%	32%
	0% to 5%	12%		0% to 5%	10%
	5% to 10%	11%		5% to 10%	10%
	10% to 15%	7%		10% to 15%	8%
	15% to 20%	8%		15% to 20%	5%
	>20%	12%		>20%	22%
Contingency based on budget (Q3.15)	< 3%	33%	Claim reserve based on Budget (Q3.16)	< 3%	85%
	3% to 6%	25%		3% to 6%	7%
	6% to 10%	20%		6% to 10%	0%
	10% to 15%	7%		10% to 15%	5%
	15% to 20%	7%		15% to 20%	1%
	>20%	8%		>20%	2%
Start-up practices (Q3.17)	Excellent	9%	Constructability practices (Q3.18)	Excellent	4%
	Above average	29%		Above average	32%
	Average	31%		Average	30%
	Somewhat	10%		Somewhat	12%
	Not effective	3%		Not effective	4%
	Unknown	18%		Unknown	18%
Risk management practices (Q3.19)	Excellent	2%	Change management practices (Q3.20)	Excellent	9%
	Above average	22%		Above average	36%
	Average	40%		Average	32%
	Somewhat	15%		Somewhat	13%
	Not effective	6%		Not effective	4%
	Unknown	15%		Unknown	6%

[a] PDRI: Project Definition Rating Index

[b] RFI: Request For Information

Human Factors

Finally, Table 16 shows 13 human factors pre-identified for the purposes of this research. Most of the questions that referred to them were designed based on a Likert-type scale. A Likert scale is commonly involved in those research based on questionnaires to rate and scale responses in survey research (Pedhazur & Schmelkin, 1991). The questions using a Likert scale are shown in Appendix A.

Table 16

Frequency Distribution of Human Factors

Characteristic	Category	%	Characteristic	Category	%
Forecaster assessment based on accuracy (Q4.1)	Agree Disagree Undecided	53% 33% 14%	Reviewer assessment Based on accuracy (Q4.2)	Agree Disagree Undecided	57% 32% 11%
Negative trends influenced on management (Q4.3)	Agree Disagree Undecided	58% 22% 20%	Negative trends motived need of scrutiny (Q4.4)	Agree Disagree Undecided	84% 6% 10%
Unchanged forecast inspired Confidence (Q4.5)	Agree Disagree Undecided	48% 26% 26%	Customer influence (Q4.11)	Strong Weak Neutral	48% 26% 26%
Reaction before adverse schedule signals (Q4.6)	Wait for more data Reduce float Further forecast Recovery/original forecasting Recovery/new forecasting	16% 31% 1% 42% 10%	Reaction before adverse cost signals (Q4.7)	Wait for more data Use of contingency Update forecast Mitigation/original budget Mitigation/new budget	21% 46% 7% 15% 11%
Reaction before positive cost signals (Q4.8)	Wait for more data Keep on the budget Adjust contingency Adjust the forecast	19% 31% 38% 12%	Forecast environment (Q4.9)	Comfortable Supportive High pressure Tense	10% 74% 14% 2%
Incentives beneficiary (Q4.12)	Control Manager Project Manager Other None	3% 22% 6% 69%	Bonus (Q4.13)	<5% 5% to 10% 10% to 20% None	8% 16% 7% 69%
Forecasting attitude (Q4.14)	Total acceptance Medium acceptance Low acceptance	53% 40% 7%			

Hypothesis Testing

To test the influencing factors, this study undertook a categorical analysis of correlation, at the significance level $\alpha = 0.05$, as explained in the section of research methodology. The Kendall's tau-b coefficient (τ_b), which is a nonparametric measure of association for ranked and non-normal variables (Agresti, 2010), indicated the strength and the direction of the relationship between predictability and the pre-identified factors.

Project Characteristics

Table l7 shows a pattern of frequency distribution along the four-segregate blocks of predictability for the variable role, which was statistically significant (τ_b = -0.178, p=0.020). Contractors showed more projects in the best scenario (Q1) and fewer projects in the worst scenario (Q4), unlike owners that showed fewer projects in Q1 and more projects in Q4.

Table 17

Frequency Distribution, Predictability by Role

		OWNER	CONTRACTOR	Total
(Q4) Predictability > .0588	Count	21	13	34
	% within Q4	62%	38%	100%
(Q3) Predictability > .0183 & <= .0588	Count	17	16	33
	% within Q3	52%	48%	100%
(Q2) Predictability >.0048 & <= .0183	Count	15	19	34
	% within Q2	44%	56%	100%
(Q1) Predictability <= .0048	Count	12	22	34
	% within Q1	35%	65%	100%
Total	Count	65	70	135
	% within Qs	48%	52%	100%

The pattern of predictability shown by role above could be due to different conditions and characteristics of the projects. Therefore, the hypothesis testing not only evaluated the association between predictability and a specific influencing factor, but evaluated a second condition that involved a third factor in the analysis. Thus, the test evaluated the influence of the variable on predictability (P), conditioned by a third variable. The study named the first condition as test of significance at variable level and the second condition as test of significance at category level. For instance, when the variable Affiliation (Q1.2) conditioned the relationship between predictability and role, this condition revealed a significant association pattern at the level of the category public, similar to the pattern shown in Table 17. Table 18 shows the pattern of frequency distribution along the four-segregate blocks of predictability for the variable, which was statistically significant (τ_b = -0.265, p=.011). Contractors showed more projects in the best scenario (Q1) and fewer projects in the worst scenario (Q4), unlike owners that showed fewer projects in Q1 and more projects in Q4.

Table 18

Frequency Distribution, Predictability by Role by Affiliation

P.1.2 Affiliation/Category: Public		OWNER	CONTRACTOR	Total
(Q4) Predictability > .0588	Count	12	2	14
	% within Q4	86%	14%	100%
(Q3) Predictability > .0183 & <= .0588	Count	10	8	18
	% within Q3	56%	44%	100%
(Q2) Predictability >.0048 & <= .0183	Count	10	9	19
	% within Q2	53%	47%	100%
(Q1) Predictability <= .0048	Count	6	9	15
	% within Q1	40%	60%	100%
Total	Count	38	28	66
	% within Qs	58%	42%	100%

Table 19 below shows the significance results at α = 0.05, at the variable level and at the category level for the remaining influencing factors of the project characteristics section. Appendix C shows the *SPSS*© outputs of the analysis for the significant factors. As a clarification note, a relationship between variables is demonstrated only when the value of the dependent variable (i.e. predictability) either increases or decreases as the independent variable (i.e. any influencing factor) increases in value. When the dependent variable increases in value as the independent variable increases in value, then the relationship is positive. On the contrary, when the dependent variable decreases in value as the independent variable increases in value, then the relationship is negative. In Table 17 and Table 18 it is noted that when the predictability increases for owners, it decreases for contractors, which indicates a negative relationship;

therefore, this study adopted as convention, that there is a negative relationship when this pattern described in Tables 17 and 18 is found between variables.

Table 19

Test of Association Project Characteristics by Predictability

Significant at Variable Level		
Kendall's tau-b coefficient (τ_b)	p value	Variable
τ_b = -0.178	p= 0.020	(Q1.1) Role: Contractor or Owner
τ_b = -0.177	p= 0.029	(Q1.3) Site location
τ_b = 0.215	p= 0.007	(Q1.4) Third party funding
τ_b = - 0.194	p= 0.010	(Q1.6) Year of completion
τ_b = 0.150	p= 0.044	(Q1.14) Project nature
τ_b = -0.114	p= 0.104	(Q1.15) Legal constraints [a]
τ_b = 0.290	p< 0.001	(Q1.17) Incentives
τ_b = -0.181	p= 0.013	Project Driver

Significant at Category Level			
Kendall's tau-b coefficient (τ_b)	p value	Variable	Category
τ_b = -0.265	p= 0.011	(Q1.2) Affiliation	Public
τ_b = -0.292	p= 0.002	(Q1.7) Project Duration	>80 weeks
τ_b = -0.256	p= 0.002	(Q1.8) Technology	Familiar
τ_b = -0.325	p= 0.004	(Q1.10) Office	Local
τ_b = -0.450	p< 0.001	(Q1.11) Project Size	>$100 MM
τ_b = -0.410	p< 0.001	(Q1.16) Payment	Lump sum

[a] Significant at α = .10

Forecasting Practices

The hypothesis testing for the factors grouped in forecasting practices involved the two conditions: testing at the variable level and at the category level as well. Table 20 below shows the significance results of association at α = 0.05 and Appendix C shows the *SPSS*© outputs of the analysis for the significant factors related to forecasting practices.

Table 20

Test of Association Forecasting Practices by Predictability

Significant at Variable Level		
Kendall's tau-b coefficient (τ_b)	p value	Variable
τ_b = 0.174	p= 0.021	(Q2.6) Team skills
τ_b = 0.144	p= 0.086	(Q2.18) Risk update [a]
τ_b = - 0.151	p= 0.059	(Q2.19) Contingency reporting [a]

Significant at Category Level			
Kendall's tau-b coefficient (τ_b)	p value	Variable	Category
τ_b = -0.310	p= 0.003	(Q2.7) Available information	Frequently
τ_b = -0.304	p= 0.001	(Q2.11) Accuracy method	None
τ_b = -0.376	p= 0.002	(Q2.13) Deviation reporting	< 1 month
τ_b = -0.775	p= 0.083	(Q2.14) Forecasting Report [a]	Monthly
τ_b = -0.287	p= 0.002	(Q2.16) Contingency budgeting	Mixed alternative
τ_b = -0.370	p< 0.001	(Q2.17) Criteria for contingency	Management judgment
τ_b = -0.331	p= 0.012	(Q2.20) Completion date reported	Most likely date

[a] Significant at $\alpha = .10$

Management Processes

The Table 21 below shows the significance results at $\alpha = 0.05$ for the management-practices-group. Appendix C shows the *SPSS*© outputs of the analysis for the significant factors.

Table 21

Test of Association Management Practices by Predictability

Significant at Variable Level		
Kendall's tau-b coefficient (τ_b)	p value	Variable
τ_b = 0.312	p< 0.001	(Q3.6) Alignment
τ_b = 0.204	p= 0.003	(Q3.7) Information integration
τ_b = -0.159	p= 0.039	(Q3.10) Strategic alliances
τ_b = 0.142	p= 0.088	(Q3.11) Integration PM-Control [a]
τ_b = -0.312	p< 0.001	(Q3.13) Schedule performance
τ_b = -0.171	p= 0.028	(Q3.14) RFIs
τ_b = -0.145	p= 0.039	(Q3.17) Start-up practices
τ_b = -0.243	p< 0.001	(Q3.20) Change management practices

Significant at Category Level			
Kendall's tau-b coefficient (τ_b)	p value	Variable	Category
τ_b = -0.194	p= 0.019	(Q3.1) FEP	Yes
τ_b = -0.554	p< 0.001	(Q3.8) Databases	NA
τ_b = -0.731	p< 0.001	(Q3.9) Change request frequency	Rarely
τ_b = -0.731	p< 0.001	(Q3.12) Cost performance reported	0% to 5%
τ_b = -0.303	p= 0.080	(Q3.18) Constructability [a]	Unknown
τ_b = -0.271	p= 0.065	(Q3.19) Risk management [a]	Above average

[a] Significant at $\alpha = .10$

Human Factors

Table 22 shows the significant results at α = 0.05 of the third variable interaction that belongs to the group of human factors. Appendix C shows the *SPSS*© outcomes of the analysis for the significant factors.

Table 22

Test of Association Human Factors by Predictability

Significant at Variable Level		
Kendall's tau-b coefficient (τ_b)	P value	Variable
τ_b = 0.141	p= 0.046	(Q4.4) Negative trends/scrutiny
τ_b = -0.121	p= 0.098	(Q4.6) Negative schedule/reaction [a]
τ_b = -0.166	p= 0.038	(Q4.7) Negative cost/reaction
τ_b = -0.168	p= 0.039	(Q4.8) Positive cost/reaction
τ_b = -0.196	p= 0.005	(Q4.9) Forecasting environment
τ_b = 0.237	p= 0.003	(Q4.12) Incentives
τ_b = 0.173	p= 0.013	(Q4.13) Bonus

Significant at Category Level			
Kendall's tau-b coefficient (τ_b)	p value	Variable	Category
τ_b = -0.418	p< 0.001	(Q4.1) Forecaster assessment /accuracy	Disagree
τ_b = -0.430	p< 0.001	(Q4.2) Reviewer assessment /accuracy	Disagree
τ_b = -0.247	p= 0.012	(Q4.3) Negative trends influence	Agree
τ_b = -0.399	p= 0.003	(Q4.5) Unchanged forecast influence	Undecided/Agree
τ_b = -0.471	p< 0.001	(Q4.11) Customer influence	Neutral
τ_b = -0.272	p= 0.016	(Q4.14) Attitude into forecasting	Medium acceptance

[a] Significant at α = .10

Probability Analysis

As noted in the former section, some pre-identified influencing factors were statistically significant either at the variable level or at the category level. There was statistically significant evidence of influence of the variable role on predictability that maybe due to different contractual interests between owners and contractors. This analysis takes into account these facts and discusses the performance of owners and contractors under each significant factor at the worst (Q4) and best (Q1) scenarios of predictability. For this analysis, RR is the risk of having projects at the worst performance estimated through a two-by-two contingency table of predictability by the influencing factor. Thus, both groups of predictability, Q1 and Q4, and the occurrence of the influencing factors associated with each group were the basis for computing RR. Specifically, RR is the probability of having an adverse impact when the factor occurs at Q4 divided by the probability of having an adverse impact when the factor occurs at Q1.

Project Characteristics

At the variable level, and based on the frequency distribution shown in Table 17, the risk analysis for the role-variable showed that an owner-project was 2.96 times more likely than a contractor-project to perform at the worst scenario (Q4) than at the best one (Q1). With 95% confidence, the probability ratio was between 1.1 and 7.9. These results demonstrate that owners faced predictability problems more frequently than contractors and owner-projects were more frequently at Q4 than contractor-projects. On the contrary, contractor-projects were more frequently at the best scenario (Q1) than those of owners. The analysis for the remaining significant variables is discussed as follows. Since owners resulted in a higher level of risk, their projects were more frequent at Q4. Thus, the indicator of reference for RR was taken regarding owners and the category more frequent at the worst scenario.

As an example at category level, Table 23 shows the frequency distribution for the variable Affiliation (Q1.2), which was significant at level of category public. Thus, it was 1.33 times more likely to find an owner-project with public affiliation at Q4 than at Q1. Furthermore, compared with contractor-projects, there was 6.0 times more probability that an owner-project that was categorized as a public project would show poor performance (Q4) than good performance (Q1). Based on the computed RR, the study estimated the average cost deviation of the projects associated with the variable Affiliation (Q1.2) and the category public and classified at Q4. The reason for choosing the average cost deviation as an indicator of impact was due to consistency of the cost forecast data observed in the sample. Finally, the study computed a risk effect indicator based on RR times average cost deviation. Table 24 shows these three values, RR (Q4/Q1), average cost deviation at Q4, and risk effect, for the remaining significant factors grouped in project characteristics.

Table 23

Frequency Distribution for the Variable Affiliation (Q1.2)

		Affiliation (Q1.2)			
		Public	Private	Both	Total
OWNER	(Q4) Predictability > .0588	12	8	1	21
		57%	38%	5%	100%
	(Q1) Predictability <= .0048	6	5	1	12
		50%	42%	8%	100%
	Total	18	14	1	33
		55%	42%	3%	100%
CONTRACTOR	(Q4) Predictability > .0588	2	10	1	13
		15%	77%	8%	100%
	(Q1) Predictability <= .0048	9	12	1	22
		41%	55%	5%	100%
	Total	11	22	2	35
		31%	63%	6%	100%

Table 24

Risk Effect for Significant Project Characteristic Factors

	OWNER			CONTRACTOR		
Variable/Category	RR Q4/Q1	Average Cost Deviation (Q4)	Risk Effect	RR Q4/Q1	Average Cost Deviation (Q4)	Risk Effect
Q Driver Schedule	0.38	0.46	0.17	0.40	.57	0.23
Q1.2/Public	1.33	0.30	0.40	0.22	.85	0.19
Q1.3/Outside	4.88	0.42	2.05	0.53	.01	0.01
Q1.4/Itself	6.67	0.35	2.31	1.40	.60	0.84
Q1.6/Before 2010	1.25	0.40	0.50	14.40	.59	7.14
Q1.7/ >80 Weeks	2.80	0.31	0.86	0.34	.70	0.24

Table 24 (con't.)

	OWNER			CONTRACTOR		
Variable/Category	RR Q4/Q1	Average Cost Deviation (Q4)	Risk Effect	RR Q4/Q1	Average Cost Deviation (Q4)	Risk Effect
Q1.8/Familiar	4.75	0.35	1.65	0.11	.54	0.06
Q1.10/Local	19.00	0.36	4.36	2.81	.73	2.06
Q1.11/ >$100MM	12.10	0.40	4.75	0.25	.64	0.16
Q1.14/Renovation	5.95	0.34	2.02	1.24	.56	0.69
Q1.15/Few Constraints	3.00	0.41	1.23	1.33	.55	0.73
Q1.16/Lump Sum	3.04	0.32	0.98	0.09	.30	0.03
Q1.17/No Incentives	20.00	0.37	4.41	3.94	.63	2.50

Based on the risk effect, Figure 13 below shows three identified levels of risk for the influencing factors, segregate by owners and contractors.

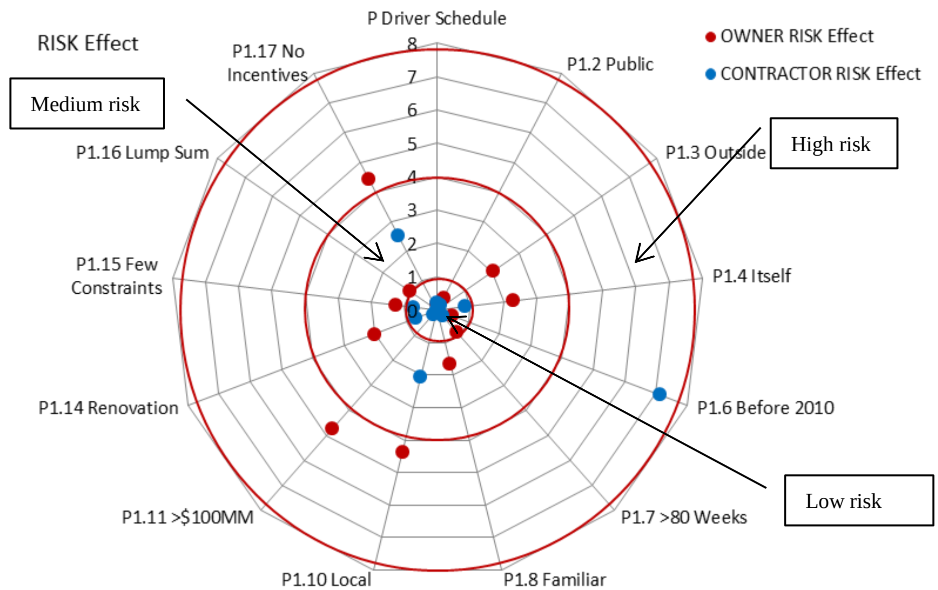

Figure 13. Map of priority for project characteristic factor risk.

The low-risk level grouped those factors with RR less than or equal to 1.0 that were the factors with low probability of occurrence at Q4. The medium-risk level factors were grouped according to those factors with RR between 1.0 and 4.0. Finally, the high-risk level factors were grouped according to the factors with RR greater than 4.0. For owners, among the high-risk level, the factors with major effect were Office Structure/ Local (Q1.10), Project Size/ >$100MM (Q1.11), and Incentives/No incentives (Q1.17), while contractors identified Project Completion/Before 2010 (Q1.6). The second level showed that owners identified Site Location/ Outside (Q1.3), Third Party Financing/itself (Q1.4), Technology/Familiar (Q1.8), Project Nature/ Renovation (Q1.14), Legal Constraints/Few (Q1.15), and Payment Strategy/Lump Sum (Q1.16) as factors of medium risk. On the other hand, contractors identified as medium risk Office Structure/Local (Q1.10) and Incentives/No incentives (Q1.17). Finally, the remaining significant factors were classified within the low level of risk, whose risk effect values were less than 1.0 point. The low level occurrence showed average occurrence less than 1.0 and average impact less than 1.0.

Forecasting Practices

Table 25 shows the values of RR (Q4/Q1), average cost deviation at Q4, and the estimate of the risk effect for the significant factors grouped in forecasting practices.

Table 25

Risk Effect for Significant Forecasting Practices Factors

	OWNER			CONTRACTOR		
Variable/Category	RR Q4/Q1	Average Cost Deviation (Q4)	Risk Effect	RR Q4/Q1	Average Cost Deviation (Q4)	Risk Effect
Q2.6/Competent	1.82	0.62	1.13	2.00	0.40	0.80
Q2.7/Frequent	1.07	0.62	0.66	0.25	0.37	0.09
Q2.11/NO	2.00	0.69	1.37	0.40	0.40	0.16
Q2.13/ < 1 Month	2.50	0.62	1.56	0.43	0.35	0.15
Q2.14/Monthly	0.29	0.64	0.18	0.71	0.38	0.27
Q2.16/Mixed	1.16	0.53	0.61	0.21	0.39	0.08

Table 25 (con't.)

	OWNER			CONTRACTOR		
Variable/Category	RR Q4/Q1	Average Cost Deviation (Q4)	Risk Effect	RR Q4/Q1	Average Cost Deviation (Q4)	Risk Effect
Q2.17/Management judgment	4.48	0.61	2.74	0.82	0.37	0.31
Q2.18/Not at all	9.00	0.87	7.85	0.27	0.43	0.11
Q2.19/Macro level	1.10	0.69	0.76	2.80	0.40	1.12
Q2.20/Most likely date	6.77	0.59	4.02	1.03	0.38	0.39

Figure 14 below shows the three levels of risk identified for forecasting practices factors. As high-level risk, owners identified Risk update/not at all (Q2.18) and Completion date reported/most likely date (Q2.20), while contractors referenced no factor within this level. A second level showed that owners identified as factors of medium risk Team skills/Competent (Q2.6), Accuracy/no assessment (Q2.11), Deviation reporting/ < 1 month (Q2.13), and Criteria for using contingency/Management judgment (Q2.17). On the other hand, contractors identified only Contingency level of revision/macro level (Q2.19) as medium risk. Finally, the remaining significant factors were classified within the low level of risk, whose risk effect values were less than 1.0 point.

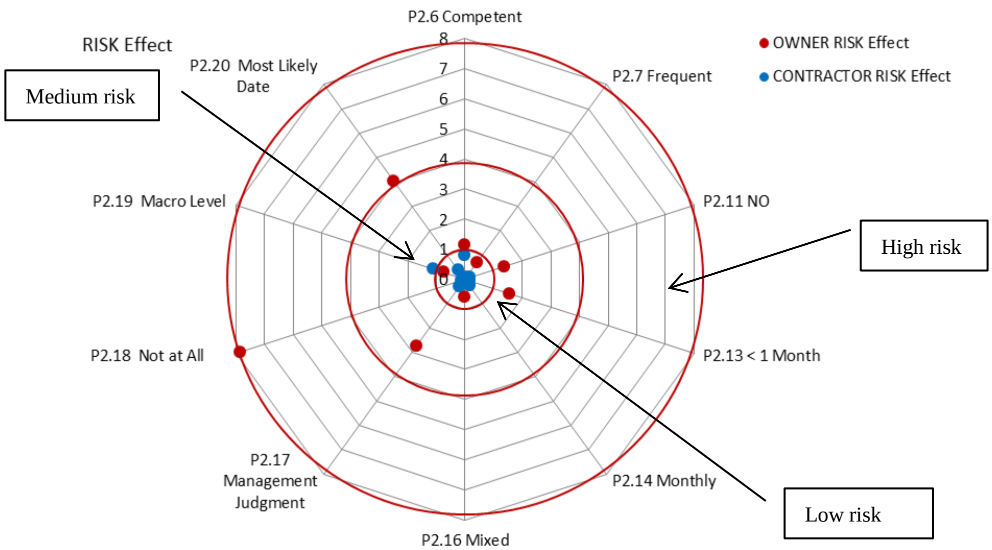

Figure 14. Map of priority for forecasting practice factor risk.

Management Practices

Table 26 shows the estimate of the risk effect for the significant factors grouped in management practices.

Table 26

Risk Effect for Significant Management Practices Factors

	OWNER			CONTRACTOR		
Variable/Category	RR Q4/Q1	Average Cost Deviation (Q4)	Risk Effect	RR Q4/Q1	Average Cost Deviation (Q4)	Risk Effect
Q3.1/YES	1.90	0.69	1.31	1.11	0.37	0.41
Q3.6/Complete	0.10	0.67	0.07	0.36	0.42	0.15
Q3.7/Satisfactory	0.62	0.69	0.42	1.11	0.29	0.32
Q3.8/Satisfactory*	0.94	0.91	0.85	1.90	0.47	0.89
QQ3.9/Occasional*	1.00	0.43	0.43	0.41	0.36	0.15
Q3.10/Satisfactory	0.94	0.62	0.58	1.22	0.44	0.54
Q3.11/YES	0.29	0.67	0.19	0.52	0.38	0.20
Q3.12/ 0% to 5%	0.16	0.95	0.15	0.94	0.36	0.34
Q3.13/ > 20%	20.00	0.39	7.89	13.33	0.24	3.19
Q3.14/Frequent	0.14	0.56	0.08	0.44	0.33	0.15
Q3.17/Above average*	0.69	0.69	0.48	0.18	0.69	0.13
Q3.18/Above average*	0.23	0.79	0.18	2.00	0.05	0.11
Q3.19/Average*	0.12	0.40	0.05	1.19	0.42	0.50
Q3.20/Average	0.32	0.49	0.16	2.81	0.54	1.52

* Categories most frequent although not significant

Figure 15 below illustrates the three levels of risk identified for forecasting practices factors. Within the high level, owners only identified as high risk Final schedule reported/ >20% (Q3.13), while contractors referenced no factors within this level. A second level indicated that owners identified as factors of medium risk Front-end-planning/yes (Q3.1) and contractors identified as medium risk Databases utilization/Satisfactory (Q3.8) and Integration control-management/Yes (Q3.11). Finally, the remaining significant factors were classified within the low level of risk, whose risk effect values were less than 1.0 point.

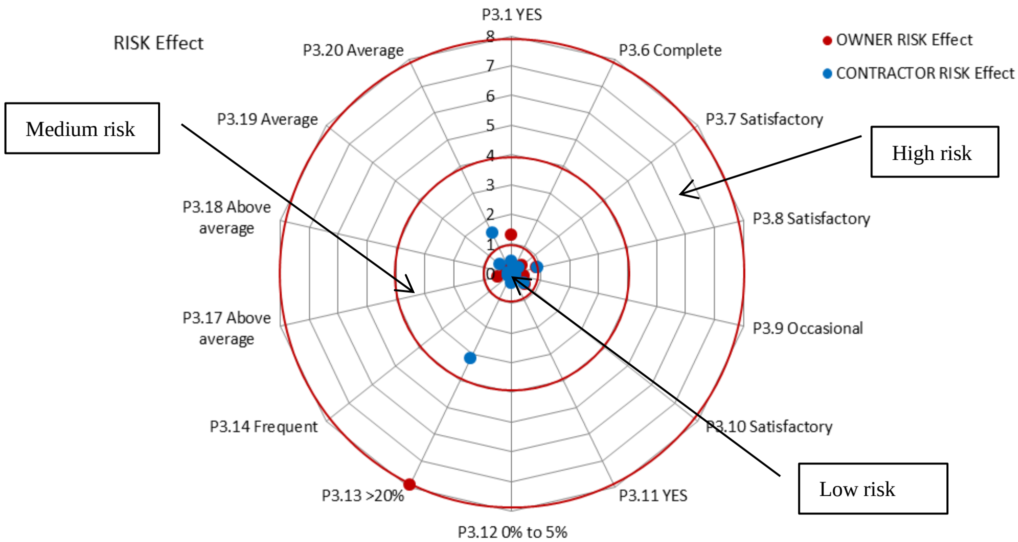

Figure 15. Map of priority for management practice factor risk.

Human Factor

Table 27 shows risk component values the significant human factors.

Table 27

Risk Effect for Significant Human Factors

	OWNER			CONTRACTOR		
Variable/Category	Risk Q4/Q1	Average Cost Deviation (Q4)	Risk Effect	Risk Q4/Q1	Average Cost Deviation (Q4)	Risk Effect
Q4.1/Disagree	4.00	0.39	1.58	0.22	0.55	0.12
Q4.2/Disagree	3.30	0.36	1.18	0.22	0.55	0.12
Q4.3/Agree	0.64	0.32	0.20	1.44	0.51	0.74
Q4.4/Agree	1.00	0.35	0.35	0.16	0.62	0.10
Q4.5/Agree	0.14	0.36	0.05	2.81	0.51	1.44
Q4.6/Schedule recovery	1.00	0.40	0.40	4.29	0.60	2.56
Q4.7/No immediate reaction	8.13	0.28	2.29	4.29	0.84	3.59
Q4.8/No immediate reaction	12.10	0.29	3.55	2.50	0.82	2.06
Q4.9/Supportive	1.20	0.42	0.50	1.29	0.66	0.85
Q4.11/Customer influence	12.10	0.34	4.07	0.78	0.73	0.57
Q4.12/Project Management	3.80	0.35	1.32	3.11	0.47	1.48
Q4.13/None	1.82	0.35	0.63	2.50	0.47	1.19
Q4.14/Low acceptance	1.27	0.51	0.64	4.81	0.70	3.38

For the significant human factors, Figure 16 shows the following levels of risk, according to the criterion used for the former factors. The high risk showed that only owners determined Customer influence (Q4.11) as a risk factor, while contractors determined no factors. The medium level of risk showed that owners identified Forecaster assessment based on accuracy/ disagree (Q4.1), Reviewer assessment based on accuracy/disagree (Q4.2), Reaction before adverse cost/No immediate reaction (Q4.7), Reaction before adverse cost/No immediate (Q4.8), and Incentives beneficiary/Project management (Q4.12), while contractors identified Unchanged forecast inspired confidence/Agree (Q4.5), Reaction before adverse schedule/Schedule recovery/original forecasting (Q4.6), Reaction before adverse cost/No immediate reaction (Q4.7), Reaction before adverse cost/No immediate (Q4.8), Incentives beneficiary/Project management (Q4.12), Bonus/None (Q4.13), and Forecasting attitude/Low acceptance (Q4.14). The remaining significant factors were classified within the low level of risk, whose risk effect values were less than 1.0 point.

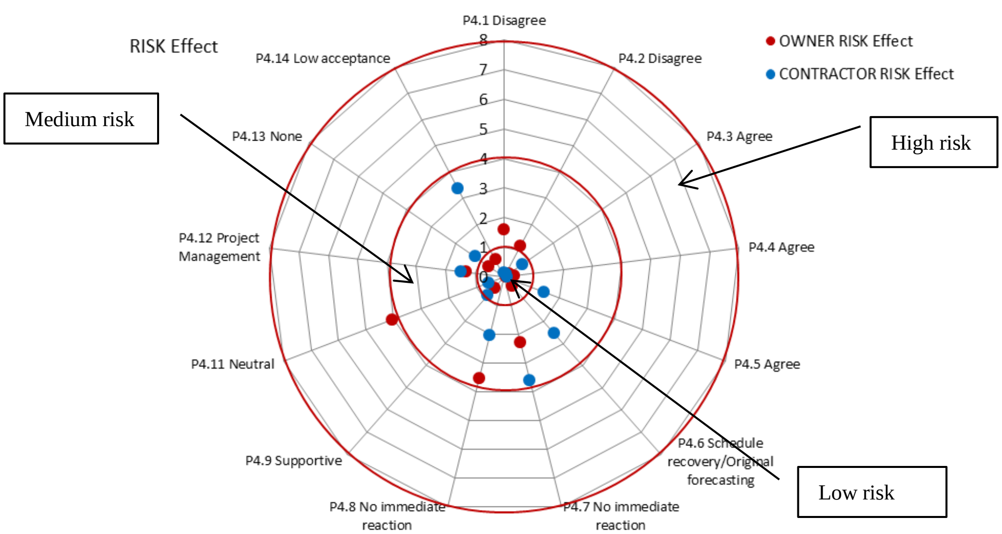

Figure 16. Map of priority for human factor risk.

CHAPTER 8

DISCUSSION AND CONTRIBUTION

The present chapter discusses the findings of this study according to the three objectives aimed: predictability index assessment, change reasons analysis, and underlying factors analysis.

Predictability Index

This study proposed to evaluate the predictability index and its component timeliness. The results demonstrated that timeliness (i.e., CT, ST) and predictability (i.e., P), understood as the addition of cost predictability index plus schedule predictability index, were significant predictors of the likelihood of achieving small cost and schedule deviations at project completion, less than 5%. In fact, there was statistically significant evidence to explain a better performance when the projects showed small values of timeliness and predictability, close to zero. It means that to achieve admissible cost and schedule deviations at completion relies on, but is not limited to, predictability; and consequently, predictability relies on timeliness and accuracy.

Thus, this study contributes to the body of knowledge in construction project management with a characterization and evaluation of the predictability indices, which might improve the efficiency and effectiveness of project management in construction. This assessment of project predictability performance through the predictability index and its two components, timeliness and aggregate deviation, shows that predictability indices close to zero indicate good performance, small timeliness, and small aggregate deviations. In other words, it indicated that early predictions detected and effectively controlled possible adverse deviations of cost and schedule of project at completion. Thus, this study recognizes that early and accurate predictions of cost and schedule might add significant value.

Change Reasons for Forecast Deviations

Since the study proved that the predictability index is significant predictor of the probability, the study was interested in identifying the most immediate reasons for those forecast deviations.

For both owners and contractors, the study pre-identified 36 change reasons related to cost and schedule forecast deviations. From these initial reasons, the study also both identified 26 change reasons with evidence enough of statistical significance of association to predictability and measured the risk effect for each one of them. The results showed that the frequency of occurrence of each change did not necessarily correspond to the impact on forecast deviations. Some changes had a high frequency of occurrence with a small impact on cost deviation mainly, while other changes had a low frequency of occurrence with a severe impact on cost performance. The study prioritized in three levels of risk the change drivers most impactful in the capital project environment regarding cost aggregate deviation (see Table 28).

Table 28

Prioritization of Change Reasons by Risk Effect

CATEGORY	OWNER	CONTRACTOR
HIGH RISK EFFECT		
A. Business (Owner driven) Scope Change		A.1 Business Drivers Change A.3 Plan Change
D. Work Planning & Execution	D.15 Construction Equipment Issues D.16 Site or Utilities Issues	
F. Control System	F.20 Scheduling Issues F.22 Project Management Issues	F.20 Scheduling Issues

Table 28 (con't.)

CATEGORY	OWNER	CONTRACTOR
HIGH RISK EFFECT		
G. Vendor/Supplier and Procurement	G.27 Logistics Issues G.28 Procurement Process Issues	G.28 Procurement Process Issues
J. Natural Threat		J.36 Acts of God
MEDIUM RISK EFFECT		
A. Business (Owner driven) Scope Change	A.3 Plan Change [a] A.4 Scope Error/Omission [a]	A.4 Scope Error/Omission [a]
B. Standard and Legal Requirements		B.8 Permitting Issues
C. Engineering Design		C.10 Design Errors/Omission C.11 Engineering Productivity
D. Work Planning & Execution	D.13 Construction Productivity D.14 Construction Errors/Omissions D.17 Work Execution -Others	D.13 Construction Productivity D.15 Equipment Issues D.16 Site or Utilities Issues D.17 Work Execution -Others
E. Startup Commissioning	E.18 Startup/Commissioning issues	
F. Control System	F.19 Cost Estimating Issues F.23 Project Team Integration Issues	F.19 Cost Estimating Issues F.21 Cost Forecasting Issues F.22 Project Management Issues F.23 Project Team Integration Issues
G. Vendor/Supplier and Procurement	G.26 Market Supply Issues	
H. Economic Conditions		H.30 Foreign exchange
LOW RISK EFFECT		
A. Business (Owner driven) Scope Change	A.1 Business Drivers Change A.2 Budget Change A.5 Business Owner driven -Other	A.2 Budget Change A.5 Business Owner -Other
B. Standard and Legal Requirements	B.6 HSSE Issues B.8 Permitting Issues	B.6 HSSE Issues
C. Engineering Design	C.10 Design Errors/Omission C.11 Engineering Productivity	
D. Work Planning & Execution		D.14 Construction Errors
E. Startup Commissioning		E.18 Startup issues
F. Control System	F.21 Cost Forecasting Issues	
G. Vendor/Supplier and Procurement	G.25 Supplier/Subcontractor Issues G.26 Market Supply Issues	G.25 Supplier Issues G.27 Logistics Issues
H. Economic Conditions	H.30 Foreign exchange	
J. Natural Threat	J.36 Acts of God	
NOT SIGNIFICANT [b] (for owners & contractors)		
B. Standard and Legal Requirements	B.7 Labor Dispute B.9. Other Legal Requirements	
C. Engineering Design	C.12 Other Engineering Design	
F. Control System	F.24 Other Control System	
G. Vendor/Supplier and Procurement	G.29 Other Vendor and Procurement	
H. Economic Conditions	H.31. Escalation/Inflation issues H.32. Other Economic Conditions	
I. Legal & Social Conditions	33. Changes in law 34. War/riots/crime/terrorism 35. Other Social Conditions	

[a] Change reasons with multicollinearity evidence
[b] There was not statistical evidence enough to claim association with predictability

Research findings for owners revealed that the most influential change categories on cost forecast deviations were (D) work planning and execution, (F) control system, and (G) vendor/supplier and procurement. Owners identified issues related to construction equipment, construction site, scheduling issues, project management issues, and procurement logistics as the most relevant reasons impacting on forecasts. Contractors' findings revealed the most influencing reasons were (A) Business (Owner driven) Scope Change, (D) work planning & execution, (F) control system, (G) vendor/supplier and procurement, and (J) natural threat. For contractors, besides acts of God, issues with relation to work site activities, scheduling, project team integration, and procurement were reasons that substantially influenced forecasts.

As medium-effect risk, owners and contractors showed agreement in identifying (A) business scope change as a change reason with considerable influence on forecasts. Every reason associated with scope change and formally accepted shall be reflected on project budget at the owner level. Therefore, the evidence of multicollinearity between them led the researcher to think that, for owners and contractors, the different expressions of business scope change have the same meaning to the extent of impact of forecasts. For owners, (B) standard and legal requirements issues were a generator of considerable risk, but not for contractors. For contractors, (C) engineering design errors and omissions produced considerable risk, while for owners this was not an important risk issue. With relation to (D) work planning & execution, for owners there was evidence they produced a medium impact, but for contractors, the same issues produced high risk; on the contrary, of those work site issues considered as high risk for owners, the perception of contractors was they were only of medium risk. The category (F) control system produced the same medium risk perception among owners and contractors, specifically with relation to issues of cost estimating/forecasting and project management. Finally, for contractors, (H) economic conditions, more specifically foreign exchange, was one of the reasons with considerable impact on forecast.

The remaining significant change reasons were perceived as low impact, which meant that for both owners and contractors, those were controllable issues. Certain events or conditions may be under direct control of the project team and there can be proactive and corrective strategies put in place to control adverse effects on outcomes of projects at completion. Finally, there were change reasons for which the study had no evidence enough to establish a statistically significant relation of association to predictability.

Influencing Factors on Forecasting Practices

Once the most immediate reasons of forecast deviations were identified, the study analyzed those underlying drivers, events, and conditions that impacted on their predictability. Following the segregation criterion based on predictability performance, the study found many statistically significant differences between the worst scenario (Q4) and the best scenario (Q1). The variable role, owners and contractors, especially, showed a statistically significant evidence of influence pattern on predictability, perhaps due to different contractual interests and requirements between them. The following sections summarize the key findings, keeping the same broad categories of project characteristics, forecasting practices, management processes, and human behaviors/organizational culture utilized through this study. These constitute a compendium of important considerations regarding the context of the predictability practices that project teams should proactively address to maximize the likelihood of accurate and timely predictions of project outcomes at completion. The categorization used to explain the findings of this study has been adapted from the CII study of predictability (Back & Grau, 2013).

Project Characteristics

Complexity and prior experience. Project complexity consists of a set of significant project attributes associated with, but not limited to, geographic location of the project (Q1.3), project completion time (Q1.7), project technology (Q1.8), approximate total installed cost at closure (Q1.11), and project nature (Q1.14).

Geographic location (Q1.3) was a significant underlying factor, considered by owners as medium risk when their projects are executed outside of the US. When locations are outside of the US, it adds to the complexity of the project delivery process and increases the uncertainty of project outcomes. Likewise, project technology (Q1.8), another significant underlying factor, was considered by owners as medium risk. The data showed evidence of influence of the level of technology maturity on predictability. With respect to project nature (Q1.14), another significant factor, it was considered by owners as medium risk factor when undertaking renovation projects. Renovation projects highly increase cost and schedule unpredictability for owner-projects. In consequence, it may be stated that contractors likely deal better with the complexity of a renovation project than owner organizations do. It is suspected that such difference arises from the likely fact that contractors typically have much better scope definition at the time they start a renovation project than an owner would. Finally, approximate total installed cost at closure (Q1.11) and project completion time (Q1.7) were significant underlying factors, considered by owners as moderate risk when the cost of the project at completion was more than $100MM and when the schedule reached more than 80 weeks for the project execution. The data indicated that long projects clearly favor the cost prediction for contractor organizations while negatively affecting the same prediction for owner organizations. In terms of schedule, though, it can be observed that short projects favor time forecasting for both contractor and owner organizations.

External influences. The study found that poor alignment among project stakeholders influenced on predictability indexes. It was also observed that when a project sponsor stated a strong preference for cost or schedule performance as a primary objective, there is potential for adverse impacts on the accuracy of future predictions of project outcomes for other success criteria. Overall, it should be stated that all projects are subject to external influences. Notwithstanding, how an organization faces such external factors determines the project predictability performance. As external influences, the study identified the following statistically significant factors: project affiliation (Q1.2), third party financing (Q1.4), legal constraints (Q1.15), payment strategy (Q1.16), and project driver.

Third party financing (Q1.4), legal constraints (Q1.15), and payment strategy (Q1.16) were statistically significant external factors, considered by owners as medium risk. When the projects are self-financed by organizations, a third party financier, in the majority of cases, introduces a rigorous control of the delivery of the project and the reported forecasts, which minimizes the likelihood of changes. Third party financiers tend to stand closely behind the project from the very first moment, so that scope is defined up-front and the project delivery process is closely monitored. When there were few or no legal requirements, owner and contractor projects were more likely to perform at the worst scenario. It meant that external legal constraints introduced a rigorous control of the delivery of the project and the reported forecasts, as well.

In addition, project affiliation (Q1.2) and project driver proved statistically significant in external factors as well, especially when the projects were public and schedule-driven. A schedule-driven project tended both to force the compression of completion schedule and to increase the number of critical path activities. Multiple activities need to run in parallel with the risk for re-work and execution errors. A domino effect propagates the costs due to the compression of the schedule. Such costs, beyond the primary or most obvious, will be very difficult to predict. Some industry sectors, such as the manufacturing or industrial sectors, are more prone to such unpredictable propagation of costs when time drives the project. Notwithstanding, owners and contractors recognized these factors as controllable issues which are under the direct control of the project team. The data indicated that long projects clearly favor the cost prediction for owner organizations while negatively affecting the same prediction for contractor organizations. In terms of schedule, though, it can be observed that short projects favor time forecasting for both contractor and owner organizations. On the other hand, results showed that lump sum contracts (Q1.16) were more likely to result in adverse cost and schedule deviations for owner projects. In fact, all worse schedule-predicted projects reported were executed under lump sum contract.

Market and economic conditions. Market and economic conditions include supplier and subcontractor issues, foreign exchange currencies issues, and escalation of project resources. Likewise, the study included unpredicted site conditions and insufficient skilled craft as another market factors. Specifically, the study identified the following statistically significant market and economic conditions: supplier/subcontractor issues (G.25), market supply issues (G.26), logistics issues (G.27), procurement process issues (G.28), foreign exchange (H.30), and year of project completion (Q1.6).

An analysis of the data collected for this study clearly showed, for both owners and contractors, that a worsening in cost predictability occurred for projects completed between 2010 and 2012. The completion date variable (Q1.6) was actually statistically correlated to predictability. According to the industry experts consulted for this study, the root cause of such correlation is most likely the instability and volatility of market conditions from 2005, especially those affecting commodity prices. In fact, the change reasons market supply issues (G.26) and foreign exchange (H.30) showed statically significant evidence of association with predictability. The large volatility of commodity prices negatively affected the ability to estimate and predict project costs. Additionally, there was evidence of influence on predictability when projects faced supplier and logistics issues (G.25, G.26, and G. 27). According the results, owners and contractors perceived logistic issues as a factor of considerable risk that adversely impacted forecast of projects' outcomes.

Project team attributes. Project team attributes showed certain influence on predictability. The study showed statistically significant evidence of association with admissible predictability performance when projects addressed alignment strategies such as project team integration issues (F.23), team forecasting skills (Q2.6), alignment (Q3.6), integrated project management information (Q3.7 and Q3.8), and local project control (Q1.10).

Project team integration issues (F.23) and team forecasting skills (Q2.6) were statistically significant influencing factors considered by contractors as a factor of considerable risk. Poor alignment (Q3.6) among project teams proved to place a risk situation. There was a clear trend toward a higher level of alignment among project teams when comparing Q4 projects with Q1 projects. It seems that a sustained culture of proper alignment leads to better project forecasts. In fact, within a local project control (Q1.10) and integrated project management information (Q3.7 and Q3.8), according to this study, a stronger consistency and application of proper alignment has a positive influence on predictability. Therefore, this study suggests that project controls should be seen as the right hand of the project manager, especially if a long-term relationship exists between the centralized project control and local project management.

Forecasting Practices

Cost and schedule forecasting methods. The study found that forecasting methods and forecasting assessment techniques differ between owners and contractors. Cost forecasting issues (F.21) was a significant change reason considered by contractors as high-risk factor and by owners as a medium-risk factor. In fact, when project predictability systems used no method for evaluating forecast accuracy (Q2.11), the likelihood of having project at the Q4 scenario was higher for owners. As well, the study evidenced that immediate reporting of deviations (Q2.13) had a positive impact on predictability. This influence of early identification and reporting of deviations is clearly exemplified among owner organizations. For such organizations, while the majority of superior predictor projects reported significant deviations within a month, a large majority of poor predictor projects was observed to report similar deviations between 1 and 6 months only. There was a clear gradation from late to early reporting between poor and superior predictor projects reported by contractor organizations.

Forecast data inputs. The provision of adequate information to generate project forecasts showed to be statistically significant factor associated with predictability. Data showed that owners had more issues getting the necessary input information to generate project cost forecasts (Q2.8). Contractors seem to perform better in collecting all the information necessary to generate a project forecast than owners (Q2.7). Notwithstanding, this study is not conclusive, which suggests that ability to collect the appropriate data to generate the forecast does not guarantee, by any means, predictability. For instance, other factors need to be present in the context of predictability such as integrated project management information (Q3.7 and Q3.8), that according to this study, showed a positive influence on predictability when a stronger consistency and application of proper alignment is achieved among project management systems.

Contingency management. Contingency management considerations were statistically significant factors influencing predictability. The results indicated that routine identification of new trends and risks to update the risk register (Q2.18) had a moderate positive impact on predictability for contractor firms. Practices that do not aim at updating the risk register in a regular manner increase the chances of poor cost predictability. However, it must be noted that in the analyzed data, practices without a regular update of the risk register were actually defined as inclusive of the project manager ability to vary reserve and contingency levels at the discretion of the manager, with no reconciliation with risk register. The results indicated the lack of a common industry practice of reconciliation of drawing down of project reserves and contingencies against the risks identified in the register. Data also suggested that for owner-projects the judgment of project manager alone in quantifying contingencies (Q2.16 and Q2.17) resulted in poor predictability. Additionally, there was evidence that more management scrutiny (Q2.19) of project reserves and contingencies results in better predictability.

Review and reporting. The study showed unequivocally that inadequate forecasting frequency is always detrimental. Review and reporting practices (Q2.13, Q2.14, and Q2.20) had statistically significant influences on the quality of the forecasting process. The evidence of immediate reporting of deviations having positive impact on predictability has been explained above. For owners, the influence of early reporting was well exemplified in the prediction of schedule. Among the superior time predictors, projects reported by owners showed twice as many projects that reported significant time deviations within a month than among poor predictors. While a third of such poor projects reported significant time deviations between 3 and 6 months, all superior predictor projects reported significant time deviations within 3 months.

Cost predictability data was also indicative of early reporting as a distinctive factor between superior and poor performers.

Management Processes

Project planning and execution. Statistically, this study showed that when front-end planning and some management practices such as risk management and change management influenced the predictions of project outcomes. The study showed statistically significant evidence of association with admissible predictability performance when projects addressed alignment strategies (Q3.6, Q3.7, Q3.8, Q3.11, and Q1.10), and management best practices (Q3.1, Q3.17, Q3.18, Q3.19, and Q3.20).

Poor alignment (Q3.6) among project teams proved to create a risk situation. There was a clear trend toward a higher level of alignment among project teams when comparing Q4 projects with Q1 projects. It seems that a sustained culture of proper alignment leads to better project forecasts. In fact, a local project control (Q1.10) and integrated project management information (Q3.7 and Q3.8), according to this study, showed that a stronger consistency and application of proper alignment had a positive influence on predictability. Therefore, this study suggests that project controls should be seen as the right hand of the project manager, especially if there is a long-term relationship between the centralized project control and local project management.

Project management practices revealed a clear positive influence on predictability, especially those management practices related to execution and control (Q3.17 and Q3.18) rather than those of planning (Q3.1). For instance, owner-projects subject to start-up, reached a higher predictability level than their contractor counterparts. For an effective implementation, start-up should be regarded as the transition from construction operations into system operations. For effective planning, proper work instructions, procedures, checklists, and/or standards to support commissioning and start-up, management practices must be available and systematically used. Overall, an above average implementation of proper start-up practices was a differentiating factor between superior and poor forecast predictors.

Contracting strategies. This study found that contract incentives improved the accuracy and timeliness of project predictions. For instance, strategic alliances satisfaction (Q3.10) was a statistically significant factor that showed the positive influence, associating a good predictability performance (Q1) when there was a satisfactory strategic alliance. Alike, factors such as third party financing (Q1.4), legal constraints (Q1.15), and payment strategy (Q1.16) explained in early sections, were issues of contracting strategies which resulted in statistical significance of influencing on predictability as well. Finally, organizational policies of incentives (Q1.17, Q4.12, and Q4.13) showed influence because different evidence of incentives through contracts and performance-based fee adjustments among key project stakeholders were statistically significant factors associated with predictability performance. The impact of contracts and performance-based fee adjustments on predictability was significant for projects reported by owner organizations. In general, it should be stated that incentives play a major role in early and accurate forecasting performance. According to subject matter experts contacted outside the research team, incentives, if well framed, can easily become drivers for predictability. The positive effect of incentives on predictability is most likely an indirect effect through a higher degree of motivation for better, and more consistent, project performance. It must be recognized that not all incentives will have a positive influence on predictability, though. Thus, incentives must be properly tailored to generate the desired performance.

Risk management. Improving the predictability of project outcomes requires effective risk management implementation (3.19). The effectiveness in the implementation of risk management practices was statistically associated with predictability. The results indicated that drawing down of contingencies and reserves is frequently not reconciled against the risk register, or is left to the criterion of a sole individual, such as the project manager. An effective implementation of risk management practices must be preceded by the proper definition of work instructions, procedures, checklists, and standards to support risk management.

Change management. Change management resulted in significant influence on project forecasting accuracy. The effective implementation of change management was a statistically significant factor associated to predictability (Q3.20). Once more, a key project management competency such as the implementation of change management practices seems to be more consistently and better applied among contractors than among owner organizations. Regardless of the degree or effectiveness of implementation, a set of proper work instructions, procedures, checklists, and/or standards to support change management practices must have been previously defined.

Human Behaviors and Organizational Culture

This study found that human behaviors and organizational culture had a statistically significant influence on the ability of project teams to predict, accurately and as soon as possible, project outcomes at completion. Human behaviors and organizational culture included a set of significant factors associated specifically with, but not limited to, the forecasting context (Q4.9, Q4.11, and Q4.14), culture of response before evident cost and schedule deviations, either positive or adverse (Q4.3, Q4.4, Q4.5, Q4.6, Q4.7, and Q4.8), organizational assessment policies on forecasting participants (Q4.1 and Q4.2), and organizational policies of incentives (Q1.17, Q4.12, and Q4.13).

The degree of cordiality within the environment under which the project forecast was reported to the client was also correlated with predictability, when the nature of the forecasting context was structured, professional, and supportive (Q4.9). Such influence holds, with differences, for both owner and contractor organizations. Results indicated that, for a majority of projects, the forecast was reported in a structured, professional, but supportive manner. These two degrees of cordiality, even though prevalent in both superior and poor project predictors, do not drive predictability. However, a high-pressure but aligned reporting environment appears to increase the cost and schedule predictability. The degree of customer influence in the generation and reporting of the forecast has been proven to be correlated with predictability (Q4.11). Any customer influence on the forecasting reporting process has a high impact on the predictability which decreases the cost and schedule predictability of contractor projects. For owner-projects, the data seem inconclusive. Low acceptance toward forecasting processes within the organization proved to be statistically significantly associated with predictability (Q4.14). Variations on the acceptance levels regarding forecasting systems did not appear to have an impact on predictability for owners, while for contractors, forecasting and project control functions are value-adding functions to the project management.

Culture of response before evident cost and schedule deviations, either positive or adverse, was characterized by fear, lacking credibility, and weak transparency in the reporting of forecast deviations (Q4.3, Q4.4, Q4.5, Q4.6, Q4.7, and Q4.8). The results showed that there is a negative perception of acceptance, when adverse forecast needs to be reported, and sometimes, unchanged forecast are not a warranty of healthy signals of the project. Project managers face much more scrutiny and negative consequences when they report negative forecasts. Nevertheless, most projects do not experience this negative scrutiny, which does not warrant a better predictability performance. Surprises and events cannot be eliminated and hence need to be accepted. In short, an attitude of awareness is suggested toward the identification and acceptance of new trends and events, either positive or negative, so that project teams obtain more realistic forecasts.

Organizational policies regarding forecasting participant assessment and incentives were statistically significant factors associated with predictability (Q1.7, Q4.1, Q4.2, Q4.12, and Q4.13). Data provided strong evidence that contract incentives improve cost predictability. Projects that rewarded their management teams for their performance had evidence of association with good predictability performance. On the contrary, projects with poor forecasting performance often had inadequate accountability for the forecasting process at an individual level. An organizational policy of incentives proved to increase, but not guarantee, cost and schedule predictability. An incentive policy needs to be designed to maintain the motivation of the individuals in the project control functions without hindering alignment. Incentives must be fair, and must be awarded when performance is achieved.

CHAPTER 9

CONCLUSION AND RECOMMENDATIONS

This study contributes to the body of knowledge in construction project management with a methodology to test, understand, measure, and deal with project predictability. The study proposes a method to assess project predictability performance and identifies those underlying drivers, events, or conditions that affect the timeliness and accuracy of project outcome predictions. In consequence, the findings of this study contribute to improved probability of achieving small cost and schedule deviations at completion, in an accurate and prompt manner. To assess the performance of project predictability, this study used a logistic regression to test the predictability index. The predictability indices are quantitative measures to determine the timeliness and accuracy of cost and schedule predictions during the execution of a project.

This study found statistically significant differences in predictability performance between owners and contractors. Contractors organizations are project oriented. Their market survival ultimately depends on their ability to effectively and efficiently deliver capital projects for owner and client organizations. Their skills and expertise are built to satisfy the project delivery process. Contractor firms continuously build experience as their whole business revolves around the delivery of projects. On the other hand, owner organizations typically observe a capital project as the means to accomplish their business operations. Thus, due to their nature, this study quantitatively proves that, actually, predictability of owner companies is much more sensitive to a large number of factors when compared to the predictability of contractor companies. Since contractor organizations depend on their ability to effectively and efficiently deliver project after project, it has been observed that contractor teams are more likely to have a much more consistent set of expertise, experience, and skills than owner teams.

Utilizing the predictability index, the data set was segregated by quartiles and quarters, which allowed identifying practices associated to early and accurate predictability, the best scenario, to be contrasted to untimely and inaccurate outcome predictions, the worst scenario. Numerous differences were found at a level of significance $\alpha = 0.05$. The analysis was further enhanced by comparing owner and contractor practices, as separate subsets, to determine differences that exist between the two with respect to practices or behaviors. As such, the study found statistical evidence enough to identify 26 change factors, for both owners and contractors, and for both cost and schedule. Next, the study prioritized these significant change reasons based on the risk effect measurement, and segregated them by owners and contractors into three levels of priority that impacted adversely on cost and schedule deviations.

Among the high risk level, for owners the change reasons with major effect were associated with category (D)—work planning and execution and category (G)—vendor, supplier, and procurement; while contractors identified, besides these two categories already enunciated, category (F)—control system and category (J)—natural threat. The medium risk level showed that while owners identified change reasons associated with category (A)—business scope change, category (B)—legal requirements, category (D)—work planning and execution, category (F)—control system, and category (G)—vendor, supplier, and procurement; contractors identified change reasons associated to category (A)—business scope change, category (C)—engineering design, category (D)—work planning and execution, category (F)—control system, and category (H) –economic conditions. The remaining significant change reasons were classified as low risk level.

Interestingly, it was observed that the frequency of occurrence of each change did not necessarily correspond to the impact or severity on the ultimate cost and schedule performance. As suspected, some changes had a high frequency of occurrence with a small impact on cost and schedule deviation, while other changes had a low frequency of occurrence with a large or severe impact on cost and schedule performance. The study ultimately identified those change drivers that were most frequent and impactful in the capital project environment. Thus, this study substantiates, with factual data, the long-held perception that the frequency of a change is likely to be inversely correlated to its negative impact on cost and schedule deviations.

Finally, the study was further enhanced by comparing owner and contractor practices, as separate subsets, to determine differences that exist between the two with respect to practices or behaviors. Project stakeholders are strongly encouraged to consider the importance of human behavior and organizational culture as explained in this study. Human behaviors and interpersonal team interactions, influenced by the culture of the organization, have the most significant and profound influence on this practice. Further, there should be recognition, as presented in research deliverables, that there are certain variables associated with project characteristics, forecasting practices, and management processes that may determine the effectiveness of cost and schedule predictions. These findings do not establish a probable cause-effect relationship (causal inference) because the study only controlled by statistical means the observations and variables and there was no experimental manipulation of them. Thus, the conclusion tells about the degree of association between two variables rather than a causality effect.

As recommendations for future research of interest and related with predictability, the author of this dissertation suggests to analyze and compare the two approaches used to compute the predictability indexes, the approach used by the CII proposal (Back & Grau 2013) who proposed the aggregated deviation based on the first forecast baseline, and the proposal used for this research where the aggregate deviation was computed based on the actual values. A second suggestion is the validation of the results found in this study by the use of statistical techniques to identify cause-effect relationships. A third suggestion is investigate and analyze the effect of the contingency management in depth in order to find similarities and differences with the approach proposed in this research.

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APPENDIX A

QUESTIONNAIRE FORMS

A.1 Project Characteristics Section

1. PROJECT CHARACTERISTICS

Project identifier (random):

1.1 Project roles or services provided by your organization. *(Check all that apply)*

- [ ] Owner/Client
- [ ] Design/Build
- [ ] Architectural/Engineering
- [ ] Procurement
- [ ] Contractor
- [ ] Construction Management

1.2 Sector affiliation:

- [ ] Public Sector
- [ ] Private Sector
- [ ] Both

1.3 Site location:

- [ ] United States
- [ ] Oceania
- [ ] Western Europe
- [ ] Asia
- [ ] Africa
- [ ] South America
- [ ] Eastern Europe
- [ ] Middle East
- [ ] Central America
- [ ] North America (Other than US)

1.4 Was this project third party financed?

- [ ] Yes
- [ ] No
- [ ] In part or to some
- [ ] Unknown

1.5 Was your company/organization new to the geographic location/region?

- [ ] Yes
- [ ] No

1.6 Approximately when was the project completed?

- [ ] 2010 to DATE
- [ ] 2005 to 2009
- [ ] 2000 to 2004
- [ ] 1995 to 1999
- [ ] 1990 to 1994

1.7 Approximate project final duration (in weeks) at completion
(Final duration of the project reported officially at closure)

1.8 Was there a new technology or process in this project ?

- [ ] Yes
- [ ] No

1.9 If yes, assess the level of familiarity with the new technology or process during design and execution

- [ ] High
- [ ] Medium
- [ ] Low

1.10 Project management office structure:

- [ ] Central project management office
- [ ] Local project management office
- [ ] Mixed (both central and local offices)

1.11 Approximate dollar value of total installed cost (US$):
(Total installed cost of the project reported officially at closure)

1.12 Project industry:

- [ ] General Building
- [ ] Pulp Paper
- [ ] Light Industrial
- [ ] Manufacturing
- [ ] Power
- [ ] Petroleum upstream
- [ ] Pharmaceutical
- [ ] Heavy Industrial
- [ ] Chemical
- [ ] Petroleum downstream
- [ ] Highway & Infrastructure
- [ ] High Tech & Electronics
- [ ] Other *(if other, please describe)*

1.13 Delivery method/strategy.

- [ ] Design/Bid/Build (traditional)
- [ ] Design/Build (EPC)
- [ ] Construction Management at Risk
- [ ] Parallel Primes
- [ ] Development
- [ ] Fast Track
- [ ] Turnkey
- [ ] Other *(if other, please describe)*

1.14 Project nature. *(Check all that apply)*

- [ ] Greenfield
- [ ] Brownfield
- [ ] Renovation/Upgrade

1.15 Regulatory/legal constraints when compared against your average project.

- [ ] Many
- [ ] Few
- [ ] None/NA

1.16 Principal project delivery payment method.

- [ ] Lump sum
- [ ] Cost Reimbursable
- [ ] Other *(if other, please describe)*

1.17 Contract incentives or performance based fee adjustments?

- [ ] Positive incentives
- [ ] Negative incentives (penalties)
- [ ] Both positive and negative incentives
- [ ] None

A.2 Forecasting Practices Section

2. FORECASTING PRACTICES

2.2 Who was responsible for providing the data/input for the project forecast? *(Check all that apply)*

- ☑ Project Manager
- ☑ Project Controls - Field
- ☑ Project Controls – Central Office
- ☑ Project Team
- ☑ Construction Manager
- ☐ Other ______ *(If other, please describe)*

2.3 Who was responsible for generating the project forecasts *(Check all that apply)*

- ☐ Project Manager
- ☑ Project Controls - Field
- ☑ Project Controls – Central Office
- ☐ Project Team
- ☐ Construction Manager
- ☐ Other ______ *(If other, please describe)*

2.4 Who reviewed and approved the information used to generate project forecasts? *(Check all that apply)*

- ☑ Project Manager
- ☑ Project Controls - Field
- ☑ Project Controls – Central Office
- ☑ Project Team
- ☑ Construction Manager
- ☐ Other ______ *(If other, please describe)*

2.5 Whom was the project forecast reported to? (i.e. who made use of the forecast?)

- ☑ Finance
- ☑ Engineering
- ☐ None/NA
- ☑ Owner
- ☑ Company Management
- ☐ Other ______ *(If other, please describe)*

2.6 For this particular project, how would you rate the skill / experience of the individual or group generating the project forecast?

- ☑ Very knowledgeable, skilled, experienced
- ☐ Satisfactory and competent
- ☐ Learning and growing professionally
- ☐ Inexperienced
- ☐ No opinion

2.7 Was the group or individual responsible for generating the forecast able to acquire all the information necessary to generate project forecasts?

- ☑ Frequently
- ☐ Occasionally
- ☐ Rarely
- ☐ Never

2.8 What data sources were used for generating the project forecasts? (Check all that apply)

- ☑ Current budget
- ☑ Physical progress reports/meetings
- ☑ Procurement log
- ☑ Project schedule
- ☑ Resource plans
- ☑ General status reports/meetings
- ☑ Change/trend log
- ☑ Risk log
- ☑ Productivity reports
- ☑ Contingency analyses
- ☑ Market/pricing trend sources
- ☑ Invoice/payment verification
- ☐ Other ______ *(If other, please describe)*

2.9 In your organization, what is the structure of the project control function?

- ☑ Dedicated at Site
- ☑ Central/Home Office
- ☐ Do not have
- ☐ Other ______ *(If other, please describe)*

2.10 What forecasting method was used?

- ☑ Earned Value system
- ☐ Time series
- ☐ Regression
- ☐ Combined methods
- ☐ Probabilistic
- ☐ Range estimating
- ☐ Other ______ *(If other, please describe)*

2.11 Was there any method used to assess the accuracy/confidence level of the forecast?

- ☐ Yes
- ☑ No

2.12 If so, what was the method used for assessing the accuracy/confidence level of the forecast?

- ☐ Final cost deviation
- ☐ Mean absolute error
- ☐ Mean square error
- ☐ Probabilistic
- ☐ Root mean square error
- ☐ Other ______ *(If other, please describe)*

2.13 Assess to what extent significant cost/schedule deviations were reported in a timely manner:

- ☑ Immediate (≤ 1 month)
- ☐ Almost immediate (1 -3 months)
- ☐ Fair/moderate (3 – 6 months)
- ☐ Delayed (6- 12 months)
- ☐ Very late (more than 12 months)
- ☐ No Reported/Unknown

2. FORECASTING PRACTICES

2.14 With which frequency was a new forecast reported?

- ☐ Weekly
- ☐ Bi-weekly
- ☑ Monthly
- ☐ Quarterly
- ☐ Annually
- ☐ Other ______ *(If other, please describe)*

2.15 To whom were the project cost and schedule at completion forecasts reported in your organization? *(check all that apply)*

- ☑ Project Team Information and Planning
- ☑ Input to Corporate Financial Reporting
- ☑ Management (Internal)
- ☐ Joint Venture Partners
- ☐ Reporting to Customer/Client
- ☐ Reporting to Third Parties (e.g. Financing Organizations)
- ☐ Reporting to Public or Government Agencies
- ☐ Other ______ *(If other, please describe)*

2.16 Describe how the project reserves and contingencies were budgeted based on specific quantified risks versus factors applied to remaining costs. *(choose the best option)*

- ☐ Completely budgeted based on specific quantified risks
- ☑ Partly budgeted based on specific quantified risks, partly budgeted based on factors applied to remaining costs
- ☐ Completely budget based on factors applied to remaining costs

2.17 Describe how the project reserves and contingencies were drawn down: *(choose the best option)*

- ☐ Against the specific quantified risks identified at the budget stage only.
- ☐ Against the specific quantified risks identified at the budget stage as well as against other cost events/trends at the project manager's discretion.
- ☑ Based on the project manager's judgment of the overall project status and direction without specific consideration to the individual risks identified at the budget stage.

2.18 Describe how the trends and new risks identified during the course of the project were quantified and added to the project risk register and forecasted contingency. *(choose the best option)*

- ☑ Routinely: A detailed project risk register is maintained throughout the project with contingency levels determined accordingly
- ☐ On a case by case basis: The project risk register may be updated periodically with major new risks for reporting purposes but contingency levels are generally managed by the project manager's judgment.
- ☐ Not at all: During the project, reserve and contingency levels are determined by the project manager's judgment with little or no tracking relative to the specific project risks identified at the budget stage.

2.19 To what level were project reserves and contingencies reported and reviewed by management during project execution?

- ☐ Not reviewed at all
- ☐ Reviewed on a macro level (e.g. percentage relative to remaining forecast spending)
- ☐ Reviewed on a line by line basis with little or no detail (e.g. risk register)
- ☑ Reviewed on a line by line basis in detail (e.g. risk probabilities and impacts)

2.20 What the forecast project completion date reported to management represented:

- ☐ The desired completion date of the project stakeholders
- ☑ The project execution team's targeted / planned completion date (i.e. project completion date reflected in the current project plan/schedule)
- ☐ The most likely completion date based on an objective analysis of project status and progress trends and data

A.3 Management Practices Section

3. RETROSPECTIVE ASSESSMENT OF PROJECT PERFORMANCE

3.1 Was a front end planning assessment tool used for the project?

☐ Yes ☐ No

3.2 Did you achieve a high level front end planning definition?

☐ Low ☐ Medium ☐ High

3.3 Did your organization perform a PDRI (project definition rating index)?

☐ Yes ☐ No ☐ Completed by others ☐ Other

(If other, please describe)

3.4 If a PDRI assessment was completed , please provide the approximate timing

☐ PDRI completed before project authorization ☐ PDRI completed after project authorization

3.5 If completed, please provide the PDRI Score:

(Please type the PDRI score)

3.6 Your assessment regarding the degree of alignment within the project team.

☐ Maintained Alignment ☐ Somewhat Maintained Alignment ☐ Varied Considerably Over Time ☐ Did Not Maintain Alignment ☐ N/A

3.7 Your assessment regarding the degree of information integration among project participants.

☐ Excellent / Consistent ☐ Satisfactory / Some issues ☐ Disappointing or Problematic ☐ Unacceptable / Very Poor ☐ N/A

3.8 Your assessment regarding the degree of utilization or implementation of database driven technologies *(such as Building Information Models)*.

☐ Much or Complete ☐ Satisfactory or Somewhat ☐ Did not Utilize or Implement ☐ Unacceptable / Very Poor ☐ N/A

3.9 How do you describe the frequency of the number of change requests:

☐ Very Frequently ☐ Frequently ☐ Occasionally ☐ Rarely ☐ Very Rarely ☐ Never

3.10 Your assessment of partnering or strategic alliances concepts employed on this project.

☐ Much or Complete ☐ Satisfactory or Somewhat ☐ Unacceptable / Very Poor ☐ Did not Utilize or Implement ☐ N/A

3.11 Did your organization effectively use tools to enable the integration of the project management and control information?

☐ Yes ☐ No

3.12 Percent final cost performance above or below authorization or cost objective (at completion):
(Please select above or below and introduce the porcentage)

☐ Above ☐ Below

3.13 Percent final schedule performance ahead or behind schedule objective (target schedule):
(Please select above or below and introduce the porcentage)

☐ Ahead ☐ Behind

3.14 How do you describe the frequency of the number of request for information RFI's:

☐ Very Frequently ☐ Frequently ☐ Occasionally ☐ Rarely ☐ Very Rarely ☐ Never

3.15 Initial authorized contingency (in US$) in the budget at project authorization

3.16 What was the approximate total dollar amount of settled or pending claims at project completion?
(Allocated amount (in US$) for claims at project authorization)

3.17 How effective was the project implementation of best Start-up Planning practices?

☐ No Reported/Unknown ☐ Not effective ☐ Somewhat ☐ Average ☐ Above average ☐ Excellent

3.18 How effective was the project implementation of best Constructability practices?

☐ No Reported/Unknown ☐ Not effective ☐ Somewhat ☐ Average ☐ Above average ☐ Excellent

3.19 How effective was the project implementation of best Risk Management practices?

☐ No Reported/Unknown ☐ Not effective ☐ Somewhat ☐ Average ☐ Above average ☐ Excellent

3.20 How effective was the project implementation of best Change Management practices?

☐ No Reported/Unknown ☐ Not effective ☐ Somewhat ☐ Average ☐ Above average ☐ Excellent

A.4 Human Factors Section

4. HUMAN FACTORS

4.1 Cost and schedule forecast accuracies were specific measures considered in the performance evaluation of the person responsible for developing the project forecasts

☐ Strongly Agree ☐ Agree ☐ Agree Somewhat ☐ Undecided ☐ Disagree Somewhat ☐ Disagree ☐ Strongly Disagree

4.2 Cost and schedule forecast accuracies were specific measures considered in the performance evaluation of the person accountable for reviewing and reporting the project forecasts.

☐ Strongly Agree ☐ Agree ☐ Agree Somewhat ☐ Undecided ☐ Disagree Somewhat ☐ Disagree ☐ Strongly Disagree

4.3 A forecast of a negative cost or schedule trend reflected poorly on the project manager at any time during the project.

☐ Strongly Agree ☐ Agree ☐ Agree Somewhat ☐ Undecided ☐ Disagree Somewhat ☐ Disagree ☐ Strongly Disagree

4.4 A forecast of a negative cost or schedule trend typically triggered more management scrutiny and involvement than a forecast of a positive cost or schedule trend.

☐ Strongly Agree ☐ Agree ☐ Agree Somewhat ☐ Undecided ☐ Disagree Somewhat ☐ Disagree ☐ Strongly Disagree

4.5 Unchanged project cost and/or completion forecasts from period to period inspired more confidence from your organization's management than changing forecasts

☐ Strongly Agree ☐ Agree ☐ Agree Somewhat ☐ Undecided ☐ Disagree Somewhat ☐ Disagree ☐ Strongly Disagree

4.6 In the event of minor delays or negative progress trends in early construction activities, which of the following best described project management reaction:

- ☐ No immediate reaction; stay the course. Wait for additional progress data before changing execution strategy or forecasting later completion date.
- ☐ No immediate reaction; stay the course. Reduce schedule float to minimize impact on the forecast completion date.
- ☐ No immediate reaction; stay the course. Forecast a later completion date by maintaining duration and float for remaining project activities.
- ☐ Implement schedule recovery measures in an attempt to meet the original project completion date. Continue forecasting the original project completion date.
- ☐ Implement schedule recovery measures in an attempt to meet the original project completion date. Forecast a new project completion date by maintaining duration and float for remaining project activities.

4.7 In the event of minor to moderate negative cost trends in early construction activities, which of the following best described project management reaction:

- ☐ No immediate reaction; stay the course. Wait for additional progress data before changing execution strategy or making significant cost forecast changes based on the observed cost trends.
- ☐ Stay the course. Offset forecast deviations to date with reserve/contingency reductions to maintain the original overall cost forecas
- ☐ Stay the course. Assume observed negative cost trends continue forward and increase the overall project forecast accordingly.
- ☐ Implement cost reduction measures and/or adjust execution strategy in an attempt to reverse negative cost trends. Maintain the original overall cost forecast based on the assumption that cost reduction measures and execution strategy changes will offset the negative cost variances accumulated to date.
- ☐ Implement cost reduction measures and/or adjust execution strategy in an attempt to reverse negative cost trends. Increase the overall project forecast based on the negative cost variances accumulated to date.

4.8 In the event of minor to moderate positive cost trends in early construction activities, which of the following best describeds project management reaction on the subject project:

- ☐ No immediate reaction; stay the course. Wait for additional progress data before changing execution strategy or making significant cost forecast changes based on the observed cost trends.
- ☐ No immediate reaction; stay the course. Maintain the original overall cost forecast on the basis that subsequent project activities may not go as well as the early project activities and offset some of the positive cost variances observed to date.
- ☐ Stay the course. Recognize positive forecast deviations to date and increase reserve/contingency levels to maintain the original overall cost forecast
- ☐ Stay the course. Assume observed positive cost trends continue forward and reduce the overall project forecast accordingly

4.9 Characterize the nature/environment under which project forecasts were reported to upper management and/or the client:

- ☐ Comfortable, cooperative, relatively informal.
- ☐ Structured, professional, but supportive.
- ☐ High pressure, stressful, but aligned.
- ☐ Tense, adversarial, critical, negative.
- ☐ Divisive, political, lacking alignment.

4.11 Assess the level of customer influence on the forecasting process or/and forecasting values

☐ Very Strong ☐ Strong ☐ Somewhat ☐ Neutral ☐ Weak ☐ Very Little Weak ☐ None

4.12 Wich of the following functions were incentivized for project performance?

☐ Control Management ☐ Project management ☐ None ☐ Other ________

(if choose other, please describe)

4.13 What was the range of salary bonus for project performance (in percentage):

☐ <5 % ☐ 5 – 10 % ☐ 10 – 20% ☐ Above 20% ☐ None

4.14 What was the project team attitude/culture toward forecasting process?

☐ Total acceptance as control tool ☐ Medium acceptance as control tool ☐ Low acceptance as control tool

A.5 Cost Forecast Deviations Section

Instructions: *follow the* ***6 steps*** *indicated below*

1. Type at the month "0" the initial budget at completion or baseline (in US$)

2. Make sure that month and cost forecast data match

3. If known, what is the total percentage of deviation cost funded by:

0%	(Total%) **by contingency**
100%	(Total%) **by approved change order**

4. For the overall project, choose the major reasons that influenced the forecast deviations

5. Rate each chosen reason according to its impact or influence level on aggregate cost deviations

6. If needed, add comments in the column "Comments"

(Follow example -Cost Example TAB)

Definitions

Cost Forecast: forecast at completion, estimated at a specific month through execution (in US$)

Baseline: cost forecast at completion, estimated in the month zero (in US$)

Last cost forecast reported may be estimated either before completion time or at completion time

Part A

COST FORECAST	
Months	**Cost Forecast US$** (at completion)
0	$819,718,728
1	$819,718,728
2	$819,718,728
3	$819,718,728
4	$819,718,728
5	$819,442,728
6	$818,358,728
7	$818,017,728
8	$822,939,728
9	$817,984,728
10	$816,872,728
11	$819,554,728
12	$819,655,728
13	$819,257,728
14	$819,704,728
15	$831,465,728
16	$837,066,728
17	$837,066,728
18	$837,066,728
19	$841,936,728
20	$841,936,728
21	$847,998,728
22	$847,998,728
23	$847,998,728
24	$858,068,728
25	$858,068,728
26	$858,259,728
27	$858,259,728
28	$861,157,228
29	$861,157,228
30	$862,360,228
31	$862,360,228
32	$868,442,228
33	$868,442,228
34	$861,835,728
35	$860,505,802
36	$860,505,802

Part B

MAIN CHANGE REASONS AND THEIR IMPACT ON AGGREGATE COST DEVIATIONS				
CATEGORY	**CHANGE REASON** *(36 options)*	**Check all that apply**	**Impact** High=10 to Low=1	**Comments** *(add comments as needed)*
A. **Business (Owner driven) Scope Change**	1. Business Drivers Change *(Capacity, reliability, policy, new technology, etc.)*	☐		
	2. Budget/Finance Change *(Schedule or strategy change)*	☑	10	
	3. Plan Change	☐		
	4. Scope Error/Omission	☐		
	5. Other	☐		
B. **Standard, Regulatory, and Legal Requirements**	6. HSSE Issues	☐		
	7. Labor Dispute	☐		
	8. Permitting Issues	☑	5	
	9. Other	☐		
C. **Engineering Design**	10. Design/Engineering Errors/Omission *(Include constructability issues)*	☐		
	11. Engineering Productivity	☑	3	
	12. Other	☐		
D. **Work Planning & Execution**	13. Construction Productivity	☑	8	
	14. Construction Errors/Omissions	☐		
	15. Construction Equipment Issues	☐		
	16. Infrastructure, Site or Utilities Issues	☐		
	17. Others	☑	5	Change in Work Execution
E. **Startup Commissioning**	18. Startup/Commissioning issues	☑	2	
F. **Control System**	19. Cost Estimating Issues *(People, process, tools, data)*	☐		
	20. Scheduling Issues *(People, process, tools, data)*	☐		
	21. Cost Forecasting Issues *(People, process, tools, data and Earned Value Analysis)*	☑	8	
	22. Project Management Issues *(People, process, data, tools; includes risk management)*	☐		
	23. Project Team Integration Issues *(Data/information exchange, communications, teamwork)*	☐		
	24. Others	☐		
G. **Vendor/Supplier and Procurement**	25. Supplier/Subcontractor Issues	☑	6	
	26. Market Supply Issues	☐		
	27. Logistics Issues	☑	3	
	28. Procurement Process Issues *(People, process, tools, data)*	☐		
	29. Others	☐		
H. **Economic Conditions**	30. Foreign exchange	☐		
	31. Escalation/Inflation issues	☐		
	32. Others	☐		
I. **Legal & Social Conditions**	33. Changes in law *(Include taxes, duties, etc.)*	☐		
	34. War/riots/crime/terrorism	☐		
	35. Others	☐		
J. **Natural Threat**	36. Acts of God: flood/earthquake/hurricane	☐		

A.6 Schedule Forecast Deviations Section

Instructions: *follow the **6 steps** indicated below*

1. Type at the month "0" the initial schedule forecast at completion or target *(in weeks)*
2. Make sure that month and schedule forecast data match
3. If known, what is the total percentage of deviation schedule allocated to:

0%	(Total%) **contingency**
100%	(Total%) **approved by change order**

4. For the overall project, choose the major reasons that influenced the forecast deviations
5. Rate each chosen reason according to its impact or influence level on aggregate schedule deviations
6. If needed, add comments in the column "Comments"
(Follow example -Schedule Example TAB)

Definitions
Schedule Forecast: time forecast at completion, estimated at a specific month through execution (weeks
Target: Time forecast at completion, estimated in the month zero (in weeks)
Last schedule forecast reported may be estimated either before completion time or at completion time

Part A

SCHEDULE FORECAST	
Months	**Schedule Forecast (weeks)** (at completion)
0	152.00
1	152.00
2	152.00
3	152.00
4	152.00
5	152.00
6	152.00
7	152.00
8	152.00
9	152.00
10	152.00
11	152.00
12	152.00
13	152.00
14	152.00
15	152.00
16	152.00
17	152.00
18	152.00
19	152.00
20	152.00
21	152.00
22	152.00
23	152.00
24	152.00
25	152.00
26	152.00
27	152.00
28	152.00
29	152.00
30	152.00
31	152.00
32	152.00
33	153.00
34	155.00
35	155.00
36	156.00
37	

Part B

MAIN CHANGE REASONS AND THEIR IMPACT ON AGGREGATE SCHEDULE DEVIATIONS				
CATEGORY	**CHANGE REASON** *(36 options)*	**Check all that apply**	**Impact High=10 to Low=1**	**Comments** *(add comments as needed)*
A. Business (Owner driven) Scope Change	**1.** Business Drivers Change *(Capacity, reliability, policy, new technology, etc.)*	☐		
	2. Budget/Finance Change *(Schedule or strategy change)*	☐		
	3. Plan Change	☐		
	4. Scope Error/Omission	☐		
	5. Other	☐		
B. Standard, Regulatory, and Legal Requirements	**6.** HSSE Issues	☐		
	7. Labor Dispute	☐		
	8. Permitting Issues	☐		
	9. Other	☐		
C. Engineering Design	**10.** Design/Engineering Errors/Omission *(Include constructability issues)*	☐		
	11. Engineering Productivity	☐		
	12. Other	☐		
D. Work Planning & Execution	**13.** Construction Productivity	☐		
	14. Construction Errors/Omissions	☐		
	15. Construction Equipment Issues	☐		
	16. Infrastructure, Site or Utilities Issues	☐		
	17. Others	☐		
E. Startup Commissioning	**18.** Startup/Commissioning issues	☑	4	
F. Control System	**19.** Cost Estimating Issues *(People, process, tools, data)*	☐		
	20. Scheduling Issues *(People, process, tools, data)*	☐		
	21. Cost Forecasting Issues *(People, process, tools, data and Earned Value Analysis)*	☐		
	22. Project Management Issues *(People, process, data, tools; includes risk management)*	☐		
	23. Project Team Integration Issues *(Data/information exchange, communications, teamwork)*	☐		
	24. Others	☐		
G. Vendor/Supplier and Procurement	**25.** Supplier/Subcontractor Issues	☑	7	
	26. Market Supply Issues	☐		
	27. Logistics Issues	☐		
	28. Procurement Process Issues *(People, process, tools, data)*	☐		
	29. Others	☐		
H. Economic Conditions	**30.** Foreign exchange	☐		
	31. Escalation/Inflation issues	☐		
	32. Others	☐		
I. Legal & Social Conditions	**33.** Changes in law *(Include taxes, duties, etc.)*	☐		
	34. War/riots/crime/terrorism	☐		
	35. Others	☐		
J. Natural Threat	**36.** Acts of God: flood/earthquake/hurricane	☐		

A.6 Change Reasons Form

MAIN CHANGE REASONS AND THEIR IMPACT ON AGGREGATE COST DEVIATIONS	
CATEGORY	**CHANGE REASON**
A. Business (Owner driven) Scope Change	1. Business Drivers Change *(Capacity, reliability, policy, new technology, etc.)*
	2. Budget/Finance Change *(Schedule or strategy change)*
	3. Plan Change
	4. Scope Error/Omission
	5. Other
B. Standard, Regulatory, and Legal Requirements	6. HSSE Issues
	7. Labor Dispute
	8. Permitting Issues
	9. Other
C. Engineering Design	10. Design/Engineering Errors/Omission *(Include constructability issues)*
	11. Engineering Productivity
	12. Other
D. Work Planning & Execution	13. Construction Productivity
	14. Construction Errors/Omissions
	15. Construction Equipment Issues
	16. Infrastructure, Site or Utilities Issues
	17. Others
E. Startup Commissioning	18. Startup/Commissioning issues
F. Control System	19. Cost Estimating Issues *(People, process, tools, data)*
	20. Scheduling Issues *(People, process, tools, data)*
	21. Cost Forecasting Issues *(People, process, tools, data and Earned Value Analysis)*
	22. Project Management Issues *(People, process, data, tools; includes risk management)*
	23. Project Team Integration Issues *(Data/information exchange, communications, teamwork)*
	24. Others
G. Vendor/Supplier and Procurement	25. Supplier/Subcontractor Issues
	26. Market Supply Issues
	27. Logistics Issues
	28. Procurement Process Issues *(People, process, tools, data)*
	29. Others
H. Economic Conditions	30. Foreign exchange
	31. Escalation/Inflation issues
	32. Others
I. Legal & Social Conditions	33. Changes in law *(Include taxes, duties, etc.)*
	34. War/riots/crime/terrorism
	35. Others
J. Natural Threat	36. Acts of God: flood/earthquake/hurricane

APPENDIX B

DEFINITION OF QUALITATIVE VARIABLES

B.1 Project Characteristics Section

Category	Variable name	Type-Scale	Section - Question
Type of company	Role	Nominal	P. Ch. (1.1)
	Affiliation	Nominal	P. Ch. (1.2)
	Management structure	Nominal	P. Ch. (1.10)
Type of project	Location	Nominal	P. Ch. (1.3)
	Unknown region	Nominal	P. Ch. (1.5)
	Completion year	Nominal	P. Ch. (1.6)
	Duration at completion	Continuous	P. Ch. (1.7)
	Technology	Nominal	P. Ch. (1.8; 1.9)
	Total installed cots	Continuous	P. Ch. (1.11)
	Industry	Nominal	P. Ch. (1.12)
	Nature	Nominal	P. Ch. (1.14)
Type of contract	Financing external stakeholders	Nominal	P. Ch. (1.4)
	Delivery method	Nominal	P. Ch. (1.13)
	Legal constraints	Nominal	P. Ch. (1.15)
	Payment method	Nominal	P. Ch. (1.16)
	Incentives	Nominal	P. Ch. (1.17)

B.2 Forecasting Practices Section

Category	Variable name	Type-Scale	Section - Question
Forecasting team	Provider of information	Nominal	F. P. (2.2)
	Forecaster	Nominal	F. P. (2.3)
	Supervisor	Nominal	F. P. (2.4)
	User	Nominal	F. P. (2.5; 2.15)
	Team Expertise/Skills	Ordinal	F. P. (2.6)
Information	Availability	Ordinal	F. P. (2.7)
	Data source	Nominal	F. P. (2.8)
Process	Method	Nominal	F. P. (2.10)
	Accuracy measure	Nominal	F. P. (2.11; 2.12)
	Reporting frequency	Ordinal	F. P. (2.13; 2.14)
	Reporting data	Nominal	F. P. (2.20)
Interrelations	Project control structure	Nominal	F. P. (2.9)
	Contingency management	Nominal	F. P. (2.16: 2.17; 2.19)
	Risk management	Nominal	F. P. (2.18)

B.3 Management Practices Section

Category	Variable name	Type-Scale	Section - Question
Project planning	FEP level	Nominal	M. P. (3.1; 3.2)
	PDRI level	Nominal	M. P. (3.3; 3.4)
	PDRI score	Continuous	M. P. (3.5)
	Alignment	Ordinal	M. P. (3.5)
Information management	Interoperability	Ordinal	M. P. (3.7; 3.11)
	Database	Ordinal	M. P. (3.8)
	RFI frequency	Ordinal	M. P. (3.14)
Change management	Change request frequency	Ordinal	M. P. (3.9)
	Change management implementation	Ordinal	M. P. (3.20)
Risk management	Partnering strategies	Ordinal	M. P. (3.10)
	Authorized contingency	Continuous	M. P. (3.15)
	Authorized Claim reserve	Continuous	M. P. (3.16)
	Risk management practices	Ordinal	M. P. (3.19)
Project control	Cost overrun	Continuous	M. P. (3.12)
	Schedule delay	Continuous	M. P. (3.13)
Execution practices	Start-up Planning	Ordinal	M. P. (3.17)
	Constructability practices	Ordinal	M. P. (3.18)

B.4 Human Factors Section

Category	Variable name	Type-Scale	Section - Question
Explicit influences	Forecast accuracy	Ordinal	H. F. (4.1; 4.2)
	Incentivized functions	Ordinal	H. F. (4.12)
	Bonus	Ordinal	H. F. (4.13)
Implicit influences	Negative trend of forecast	Ordinal	H. F. (4.3; 4.4)
	Unchanged trend of forecast	Ordinal	H. F. (4.5)
	Customer influence	Ordinal	H. F. (4.11)
Reactions	Before early minor deviations and negative trends	Ordinal	H. F. (4.6; 4.7)
	Before early positive trends	Ordinal	H. F. (4.8)
Work climate and culture	Forecasting culture and work climate	Ordinal	H. F. (4.9)
	Team attitude	Ordinal	H. F. (4.14)

B.5 Change Reasons Form

Category	Variable name	Type-Scale	Section - Question
Change Reasons (36 questions)	Change reasons related to owner/Scope change	Ordinal	Category A; Change reason (A.1 to A.5)
	Legal requirements	Ordinal	Category B; Change reason (B.6 to B.9)
	Engineering design	Ordinal	Category C; Change reason (C.10 to C.12)
	Work planning & execution	Ordinal	Category D; Change reason (D.13 to D.17)
	Startup & commissioning	Ordinal	Category E; Change reason (E.18)
	Control System	Ordinal	Category F; Change reason (F.19 to F.24)
	Suppliers & procurement	Ordinal	Category G; Change reason (G.25 to G.29)
	Economic conditions	Ordinal	Category H; Change reason (H.30 to H.32)
	Legal & social conditions	Ordinal	Category I; Change reason (I.33 to I.35)
	Natural threat	Ordinal	Category J; Change reason (J.36)

APPENDIX C

SPSS© (VERSION 19) OUTPUTS

C.1 Hypothesis 1: Predictability Index

C.1.1 Basic Statistics of the Predictability Predictors, Segregated by Q1 and Q4

Variable	Group	N	Mean	S. D.	S. E. Mean	Min	Max	Range	Kurtosis	S. E. K.	Skewness	S. E. S.
Predictability	1st Quarter Predictability <= 0.004788)	34	.001823	.0014401	.0002470	.0000	.0048	.0048	-.927	.788	.483	.403
	4th Quarter Predictability >=0.058761)	34	.156163	.0658338	.0112904	.0588	.2689	.2102	-1.316	.788	-.082	.403
C_Timeliness	1st Quarter (Predictability <= 0.004788)	34	.017421	.0119215	.0020445	.0009	.0420	.0411	-1.035	.788	.487	.403
	4th Quarter (Predictability >=0.058761)	34	.160221	.0993003	.0170299	.0080	.3380	.3300	-1.099	.788	.097	.403
C_Deviation	1st Quarter (Predictability <= 0.004788)	34	.049317	.0326929	.0056068	.0017	.1239	.1222	-.078	.788	.618	.403
	4th Quarter (Predictability >=0.058761)	34	.462930	.3070053	.0526510	.0010	.9505	.9495	-1.267	.788	.114	.403
S_Timeliness	1st Quarter (Predictability <= 0.004788)	34	.016488	.0211531	.0036277	.0000	.0628	.0628	-.745	.788	.906	.403
	4th Quarter (Predictability >=0.058761)	34	.174716	.0958529	.0164386	.0000	.3222	.3222	-1.021	.788	-.046	.403
S_Deviation	1st Quarter (Predictability <= 0.004788)	34	.020788	.0273698	.0046939	.0000	.0865	.0865	.023	.788	1.141	.403
	4th Quarter (Predictability >=0.058761)	34	.346647	.1846347	.0316646	.0000	.6250	.6250	-.646	.788	-.325	.403

C.1.2 Logistic Regression (Predictability, Cost and Schedule Deviations ≤ 5%)

Variables in the Equation

		B	S.E.	Wald	df	Sig.
Step 1[a]	Predictability	-1408.079	527.559	7.124	1	.008
	Constant	2.420	1.061	5.209	1	.022

a. Variable(s) entered on step 1: Predictability.

Classification Table[c]

			Predicted					
			Selected Cases[a]			Validation Cases[b]		
			Admissible Deviations		Percentage Correct	Admissible Deviations		Percentage Correct
	Observed		0 (NO)	1 (YES)		0 (NO)	1 (YES)	
Step 1	Admissible Cost & Schedule Deviations	0 (NO)	81	3	96.4	33	1	97.1
		1 (YES)	1	9	90.0	1	6	85.7
	Overall Percentage				95.7			95.1

a. Selected cases Validate EQ 1
b. Unselected cases Validate NE 1
c. The cut value is .500

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	45.233	1	.000
	Block	45.233	1	.000
	Model	45.233	1	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	18.477[a]	.382	.776

a. Estimation terminated at iteration number 14 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	.960	8	.998

C.1.3 Logistic Regression (Cost Timeliness, Cost Deviation ≤ 5%)

Variables in the Equation

		B	S.E.	Wald	df	Sig.
Step 1[a]	CT	-130.977	33.621	15.177	1	.000
	Constant	2.382	.714	11.143	1	.001

a. Variable(s) entered on step 1: CT

Classification Table[c]

			Predicted					
			Selected Cases[a]			Validation Cases[b]		
			Admissible Deviations		Percentage Correct	Admissible Deviations		Percentage Correct
	Observed		0 (NO)	1 (YES)		0 (NO)	1 (YES)	
Step 1	Admissible Cost Deviation	0 (NO)	63	8	88.7	28	2	93.3
		1 (YES)	5	18	78.3	4	7	63.6
	Overall Percentage				86.2			85.4

a. Selected cases Validate EQ 1
b. Unselected cases Validate NE 1
c. The cut value is .500

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	56.135	1	.000
	Block	56.135	1	.000
	Model	56.135	1	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	48.471[a]	.450	.670

a. Estimation terminated at iteration number 14 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	2.116	8	.977

C.1.4 Logistic Regression (Schedule Timeliness, Schedule Deviation $\leq$ 5%)

Variables in the Equation

		B	S.E.	Wald	df	Sig.
Step 1[a]	ST	-59.489	13.885	18.356	1	.000
	Constant	1.732	.542	10.204	1	.001

a. Variable(s) entered on step 1: CT_25

Classification Table[c]

Observed			Predicted					
			Selected Cases[a]			Validation Cases[b]		
			Admissible Deviations		Percentage Correct	Admissible Deviations		Percentage Correct
			0 (NO)	1 (YES)		0 (NO)	1 (YES)	
Step 1	Admissible Schedule Deviation	0 (NO)	63	5	92.6	19	3	86.4
		1 (YES)	5	21	80.8	2	17	89.5
	Overall Percentage				89.4			87.8

a. Selected cases Validate EQ 1
b. Unselected cases Validate NE 1
c. The cut value is .500

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	55.525	1	.000
	Block	55.525	1	.000
	Model	55.525	1	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	55.340[a]	.446	.644

a. Estimation terminated at iteration number 14 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	46.984	8	.000

C.2 Hypothesis 2: Change Reasons of Deviations

C.2.1 Correlation Analysis (Predictability, Change Reasons)

Correlations

			Predictability	A.1	A.2	A.3	A.4	A.5	B.6	B.7	B.8	B.9	C.10	C.11	C.12	D.13	D.14	D.15	D.16	D.17
Kendall's tau_b	Predictability	Correlation Coefficient	1.000	.522**	.487**	.614**	.711**	.474**	.710**	1.000	.657**	.619*	.543**	.665**	-.286	.541**	.560**	.754**	.657**	.517**
		Sig. (1-tailed)	.	.000	.000	.000	.000	.001	.000	.	.008	.025	.000	.000	.161	.000	.003	.000	.000	.003
		N	135	26	31	58	45	22	13	2	9	7	60	35	8	66	14	19	17	16
	A.1	Correlation Coefficient	.522**	1.000	1.000**	.636**	.764**	-1.000	.333	.	1.000**	.	.591**	.745**	1.000	.491*	.690*	.	1.000*	1.000
		Sig. (1-tailed)	.000	.	.	.002	.004	.	.301	.	.	.	.001	.001	.	.018	.028	.	.	.
		N	26	26	5	12	8	2	3	0	5	1	16	11	3	11	6	1	4	2
	A.2	Correlation Coefficient	.487**	1.000**	1.000	.927**	.930**	.467*	.	.	1.000	1.000	.930**	.867**	.	.557**	.548	1.000	.	.333
		Sig. (1-tailed)	.000	.	.	.000	.000	.030	.	.	.	.	.000	.000	.	.000	.139	.	.	.248
		N	31	5	31	11	9	10	0	1	3	3	9	10	0	23	4	3	1	4
	A.3	Correlation Coefficient	.614**	.636**	.927**	1.000	.623**	-.333	.878**	.	1.000**	.333	.558**	.818**	.333	.586**	.764**	.333	.000	.000
		Sig. (1-tailed)	.000	.002	.000	.	.000	.301	.003	.	.	.301	.000	.000	.301	.000	.001	.301	.500	.500
		N	58	12	11	58	23	3	7	0	5	3	32	14	3	25	10	3	8	6
	A.4	Correlation Coefficient	.711**	.764**	.930**	.623**	1.000	.733*	.143	.	1.000	1.000	.734**	.848**	.800*	.723**	.722**	.911**	.000	.600
		Sig. (1-tailed)	.000	.004	.000	.000	.	.019	.326	.	.	.	.000	.000	.025	.000	.003	.000	.500	.071
		N	45	8	9	23	45	6	7	1	2	2	29	12	5	28	9	10	9	5
	A.5	Correlation Coefficient	.474**	-1.000**	.467*	-.333	.733*	1.000	.	.	.	1.000	.714*	.467	1.000	.347*	1.000	.	1.000	1.000*
		Sig. (1-tailed)	.001	.	.030	.301	.019	.	.	.	.	.	.012	.094	.	.026	.	.	.	.
		N	22	2	10	3	6	22	1	0	0	2	7	6	2	17	2	0	3	4
	B.6	Correlation Coefficient	.710**	.333	.	.878**	.143	.	1.000	.	.	.	.685**	.781**	-1.000	.500*	.	1.000	.	1.000
		Sig. (1-tailed)	.000	.301	.	.003	.326	.	.	.	.	.	.002	.008	.	.017	.	.	.	.
		N	13	3	0	7	7	1	13	0	0	1	11	7	2	11	1	2	1	2
	B.7	Correlation Coefficient	1.000**	.	.	.	.	.	.	1.000	.	.	.	.	.	1.000	.	.	.	.
		Sig. (1-tailed)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		N	2	0	1	0	1	0	0	2	0	0	1	0	0	2	0	1	0	0
	B.8	Correlation Coefficient	.657**	1.000**	1.000**	1.000**	1.000**	.	.	.	1.000	.	.600*	1.000	.	1.000*	1.000	.	-1.000	.
		Sig. (1-tailed)	.008	.	.	.	.	.	.	.	.	.	.033	.	.	.	.	.	.	.
		N	9	5	3	5	2	0	0	0	9	0	7	3	0	4	2	1	2	1
	B.9	Correlation Coefficient	.619*	.	1.000**	.333	1.000**	1.000**	.	.	.	1.000	.000	1.000	.	.800*	.	.	1.000	-1.000
		Sig. (1-tailed)	.025	.	.	.301	.	.	.	.	.	.	.500	.	.	.025	.	.	.	.
		N	7	1	3	3	2	2	1	0	0	7	4	2	1	5	1	0	2	3
	C.10	Correlation Coefficient	.543**	.591**	.930**	.558**	.734**	.714*	.685**	.	.600*	.000	1.000	.598**	1.000	.585**	.670**	.878**	.514*	.556*
		Sig. (1-tailed)	.000	.001	.000	.000	.000	.012	.002	.	.033	.500	.	.000	.	.000	.000	.003	.014	.019
		N	60	16	9	32	29	7	11	1	7	4	60	19	3	31	14	7	11	9
	C.11	Correlation Coefficient	.665**	.745**	.867**	.818**	.848**	.467	.781**	.	1.000**	1.000**	.598**	1.000	.	.796**	1.000	1.000	.333	.389
		Sig. (1-tailed)	.000	.001	.000	.000	.000	.094	.008	.	.	.	.000	.	.	.000	.	.	.301	.072
		N	35	11	10	14	12	6	7	0	3	2	19	35	0	22	3	3	3	9
	C.12	Correlation Coefficient	-.286	1.000**	.	.333	.800*	1.000**	-1.000**	.	.	.	1.000**	.	1.000	.667	.	.	.000	1.000
		Sig. (1-tailed)	.161	.	.	.301	.025	.	.	.	.	.	.	.	.	.087	.	.	.500	.
		N	8	3	0	3	5	2	2	0	0	1	3	0	8	4	1	1	4	2
	D.13	Correlation Coefficient	.541**	.491*	.557**	.586**	.723**	.347*	.500*	1.000**	1.000**	.800*	.585**	.796**	.667	1.000	.619*	.748**	.090	.595**
		Sig. (1-tailed)	.000	.018	.000	.000	.000	.026	.017	.	.	.025	.000	.000	.087	.	.025	.000	.360	.004
		N	66	11	23	25	28	17	11	2	4	5	31	22	4	66	7	12	10	12
	D.14	Correlation Coefficient	.560**	.690*	.548	.764**	.722**	1.000**	.	.	1.000**	.	.670**	1.000**	.	.619*	1.000	1.000	1.000	.
		Sig. (1-tailed)	.003	.028	.139	.001	.003	.	.	.	.	.	.000	.	.	.025	.	.	.	.
		N	14	6	4	10	9	2	1	0	2	1	14	3	1	7	14	2	3	1
	D.15	Correlation Coefficient	.754**	.	1.000**	.333	.911**	.	1.000**	.	.	.	.878**	1.000**	.	.748**	1.000**	1.000	-1.000	1.000
		Sig. (1-tailed)	.000	.	.	.301	.000	.	.	.	.	.	.003	.	.	.000	.	.	.	.
		N	19	1	3	3	10	0	2	1	1	0	7	3	1	12	2	19	2	2
	D.16	Correlation Coefficient	.657**	1.000**	.	.000	.000	1.000**	.	.	-1.000**	1.000**	.514*	.333	.000	.090	1.000**	-1.000**	1.000	-.816
		Sig. (1-tailed)	.000	.	.	.500	.500	.	.	.	.	.	.014	.301	.500	.360	.	.	.	.110
		N	17	4	1	8	9	3	1	0	2	2	11	3	4	10	3	2	17	3
	D.17	Correlation Coefficient	.517**	1.000**	.333	.000	.600	1.000**	1.000**	.	.	-1.000**	.556*	.389	1.000**	.595**	.	1.000**	-.816	1.000
		Sig. (1-tailed)	.003	.	.248	.500	.071	.	.	.	.	.	.019	.072	.	.004	.	.	.110	.
		N	16	2	4	6	5	4	2	0	1	3	9	9	2	12	1	2	3	16

**. Correlation is significant at the 0.01 level (1-tailed).
*. Correlation is significant at the 0.05 level (1-tailed).

Correlations

			Predictability	E.18	F.19	F.20	F.21	F.22	F.23	F.24	G.25	G.26	G.27	G.28	G.29	H.30	H.31	H.32	I.33	I.34	I.35	J.36
Kendall's tau_b	Predictability	Correlation Coefficient	1.000	.533**	.528**	.714**	.636**	.560**	.648**	.600*	.562**	.489**	.560**	.417*	.524*	.810**	.167	1.000	1.000	.	.	.584**
		Sig. (1-tailed)	.	.000	.000	.000	.003	.003	.008	.045	.000	.008	.003	.012	.049	.005	.266	.	.	.	.	.003
		N	135	35	31	21	11	14	9	6	45	14	14	16	7	7	9	2	2	0	1	13
	E.18	Correlation Coefficient	.533**	1.000	.400	.333	1.000	1.000	1.000	.	.731**	.333	1.000	.667	-.333	.800*	.333	.	.	.	.	.556
		Sig. (1-tailed)	.000	.	.164	.248	.	.	.	.	.000	.217	.	.087	.248	.025	.301	.	.	.	.	.097
		N	35	35	5	4	2	2	2	0	19	5	2	4	4	5	3	0	1	0	0	5
	F.19	Correlation Coefficient	.528**	.400	1.000	.143	.733*	1.000	1.000	1.000*	.477*	1.000	-.333	-.333	.	1.000	.333	1.000	.	.	.	.333
		Sig. (1-tailed)	.000	.164	.	.310	.019	.	.	.	.021	.	.301	.248	.	.	.248	.	.	.	.	.248
		N	31	5	31	8	6	2	3	4	11	2	3	4	1	3	4	2	1	0	0	4
	F.20	Correlation Coefficient	.714**	.333	.143	1.000	.600	.667	.238	.	.511*	.667	.000	.667	.	.	1.000	.	.	.	.	.667
		Sig. (1-tailed)	.000	.248	.310	.	.071	.087	.226	.	.020	.087	.500	.087	.	.	.	.	.	.	.	.087
		N	21	4	8	21	5	4	7	0	10	4	4	4	0	1	3	1	1	0	1	4
	F.21	Correlation Coefficient	.636**	1.000**	.733*	.600	1.000	1.000	1.000	.	1.000**	1.000	.333	1.000	.	.	1.000**	.	.	.	.	1.000
		Sig. (1-tailed)	.003	.	.019	.071	.	.	.	.	.	.	.301	.	.	.	.	.	.	.	.	.
		N	11	2	6	5	11	2	3	1	6	2	3	2	0	0	5	1	1	0	1	2
	F.22	Correlation Coefficient	.560**	1.000**	1.000**	.667	1.000**	1.000	1.000	.	.667	1.000	.800*	.600	.	.	.	.	.	.	.	.
		Sig. (1-tailed)	.003	.	.	.087	.	.	.	.	.087	.	.025	.071	.	.	.	.	.	.	.	.
		N	14	2	2	4	2	14	2	0	4	3	5	5	0	0	1	1	0	0	0	1
	F.23	Correlation Coefficient	.648**	1.000**	1.000**	.238	1.000**	1.000**	1.000	.	.524*	.	.	1.000	.	.	1.000	.	.	.	.	.333
		Sig. (1-tailed)	.008	.	.	.226	.	.	.	.	.049	.	.	.	.	.	.	.	.	.	.	.301
		N	9	2	3	7	3	2	9	0	7	1	1	3	0	0	2	0	0	0	1	3
	F.24	Correlation Coefficient	.600*	.	1.000**	.	.	.	.	1.000	1.000	.	.	.333	.	.	.	.	.	.	.	1.000
		Sig. (1-tailed)	.045	.	.	.	.	.	.	.	.	.	.	.301	.	.	.	.	.	.	.	.
		N	6	0	4	0	1	0	0	6	2	1	1	3	1	1	1	0	1	0	0	2
	G.25	Correlation Coefficient	.562**	.731**	.477*	.511*	1.000**	.667	.524*	1.000**	1.000	.467	.400	.429	-.400	.333	.867**	.	1.000	.	.	.546*
		Sig. (1-tailed)	.000	.000	.021	.020	.	.087	.049	.	.	.094	.164	.088	.164	.301	.007	.	.	.	.	.031
		N	45	19	11	10	6	4	7	2	45	6	5	7	5	3	6	1	2	0	1	8
	G.26	Correlation Coefficient	.489**	.333	1.000**	.667	1.000**	1.000**	.	.	.467	1.000	1.000	.333	.	1.000	1.000	.	1.000	.	.	-.200
		Sig. (1-tailed)	.008	.217	.	.087	.	.	.	.	.094	.	.	.301	.	.	.	.	.	.	.	.351
		N	14	5	2	4	2	3	1	1	6	14	3	3	0	2	3	0	2	0	0	4
	G.27	Correlation Coefficient	.560**	1.000**	-.333	.000	.333	.800*	.	.	.400	1.000**	1.000	-1.000	.	.	.	.	.	.	.	1.000
		Sig. (1-tailed)	.003	.	.301	.500	.301	.025	.	.	.164	.	.	.	.	.	.	.	.	.	.	.
		N	14	2	3	4	3	5	1	1	5	3	14	2	0	0	1	0	1	0	0	2
	G.28	Correlation Coefficient	.417*	.667	-.333	.667	1.000**	.600	1.000**	.333	.429	.333	-1.000**	1.000	.	1.000	1.000	.	-1.000	.	.	.333
		Sig. (1-tailed)	.012	.087	.248	.087	.	.071	.	.301	.088	.301	.	.	.	.	.	.	.	.	.	.301
		N	16	4	4	4	2	5	3	3	7	3	2	16	0	2	2	0	2	0	0	3
	G.29	Correlation Coefficient	.524*	-.333	.	.	.	.	.	.	-.400	.	.	.	1.000	.	.	.	.	.	.	.
		Sig. (1-tailed)	.049	.248	.	.	.	.	.	.	.164	.	.	.	.	.	.	.	.	.	.	.
		N	7	4	1	0	0	0	0	1	5	0	0	0	7	1	1	0	0	0	0	1
	H.30	Correlation Coefficient	.810**	.800*	1.000**	.	.	.	.	.	.333	1.000**	.	1.000**	.	1.000	-1.000	.	.	.	.	.
		Sig. (1-tailed)	.005	.025	.	.	.	.	.	.	.301	.	.	.	.	.	.	.	.	.	.	.
		N	7	5	3	1	0	0	0	1	3	2	0	2	1	7	2	1	1	0	0	1
	H.31	Correlation Coefficient	.167	.333	.333	1.000**	1.000**	.	1.000**	.	.867**	1.000**	.	1.000**	.	-1.000**	1.000	.	.	.	.	1.000
		Sig. (1-tailed)	.266	.301	.248	.	.	.	.	.	.007	.	.	.	.	.	.	.	.	.	.	.
		N	9	3	4	3	5	1	2	1	6	3	1	2	1	2	9	0	1	0	1	2
	H.32	Correlation Coefficient	1.000**	.	1.000**	.	.	.	.	.	.	.	.	.	.	.	.	1.000	.	.	.	.
		Sig. (1-tailed)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		N	2	0	2	1	1	1	0	0	1	0	0	0	0	1	0	2	0	0	0	0
	I.33	Correlation Coefficient	1.000**	.	.	.	.	.	.	.	1.000**	1.000**	.	-1.000**	.	.	.	.	1.000	.	.	.
		Sig. (1-tailed)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		N	2	1	1	1	1	0	0	1	2	2	1	2	0	1	1	0	2	0	0	1
	I.34	Correlation Coefficient	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		Sig. (1-tailed)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		N	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	I.35	Correlation Coefficient	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		Sig. (1-tailed)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		N	1	0	0	1	1	0	1	0	1	0	0	0	0	0	1	0	0	0	1	0
	J.36	Correlation Coefficient	.584**	.556	.333	.667	1.000**	.	.333	1.000**	.546*	-.200	1.000**	.333	.	.	1.000**	.	.	.	.	1.000
		Sig. (1-tailed)	.003	.097	.248	.087	.	.	.301	.	.031	.351	.	.301	.	.	.	.	.	.	.	.
		N	13	5	4	4	2	1	3	2	8	4	2	3	1	1	2	0	1	0	0	13

**. Correlation is significant at the 0.01 level (1-tailed).
*. Correlation is significant at the 0.05 level (1-tailed).

C.2.2 Relative Risk Analysis (Predictability, Change Reasons)

Variable Q1.1 Role

Predictability * Role

			Role		Total
			CONTRACTOR	OWNER	
Quarter	(Q4) Predictability > .0588	Count	13a	21a	34
		% within Quarter	38.2%	61.8%	100.0%
	(Q3) Predictability > .0183 & <= .0588	Count	16a	17a	33
		% within Quarter	48.5%	51.5%	100.0%
	(Q2) Predictability >.0048 & <= .0183	Count	19a	15a	34
		% within Quarter	55.9%	44.1%	100.0%
	(Q1) Predictability <= .0048	Count	22a	12a	34
		% within Quarter	64.7%	35.3%	100.0%
Total		Count	70	65	135
		% within Quarter	51.9%	48.1%	100.0%

Each subscript letter denotes a subset of Role categories whose column proportions do not differ significantly from each other at the .05 level.

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Ordinal by Ordinal	Kendall's tau-b	.178	.076	2.331	.020
	Kendall's tau-c	.218	.093	2.331	.020
N of Valid Cases		135			

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

A1 Business Drivers Change

		Occurrence A1		
		YES	NO	Total
CONTRACTOR	Predictability > .004788	8	40	48
		17%	83%	100%
	Predictability <= .004788	2	20	22
		9%	91%	100%
OWNER	Predictability > .004788	11	42	53
		21%	79%	100%
	Predictability <= .004788	5	7	12
		42%	58%	100%

A.1

	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	8	6.01
	Predictability <= .004788	2	0.15
	Total	10	4.84
OWNER	Predictability > .004788	11	1.73
	Predictability <= .004788	5	0.46
	Total	16	1.33
Total	Predictability > .004788	19	3.53
	Predictability <= .004788	7	0.37
	Total	26	2.68

A2 Budget/Finance Change

		Occurrence A2		
		YES	NO	Total
CONTRACTOR	Predictability > .004788	14	34	48
		29%	71%	100%
	Predictability <= .004788	11	11	22
		50%	50%	100%
OWNER	Predictability > .004788	5	48	53
		9%	91%	100%
	Predictability <= .004788	1	11	12
		8%	92%	100%

A.2

	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	14	3.67
	Predictability <= .004788	11	.33
	Total	25	2.20
OWNER	Predictability > .004788	5	.76
	Predictability <= .004788	1	.24
	Total	6	.67
Total	Predictability > .004788	19	2.90
	Predictability <= .004788	12	.32
	Total	31	1.90

A3 Plan Change

		Occurrence A3		
		YES	NO	Total
CONTRACTOR	Predictability > .004788	27	21	48
		56%	44%	100%
	Predictability <= .004788	9	13	22
		41%	59%	100%
OWNER	Predictability > .004788	19	34	53
		36%	64%	100%
	Predictability <= .004788	3	9	12
		25%	75%	100%

A.3

	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	27	4.37
	Predictability <= .004788	9	.27
	Total	36	3.35
OWNER	Predictability > .004788	19	1.98
	Predictability <= .004788	3	.30
	Total	22	1.75
Total	Predictability > .004788	46	3.38
	Predictability <= .004788	12	.28
	Total	58	2.74

A4 Scope Error/Omission

		Occurrence A4		
		YES	NO	Total
CONTRACTOR	Predictability > .004788	13	35	48
		27%	73%	100%
	Predictability <= .004788	4	18	22
		18%	82%	100%
OWNER	Predictability > .004788	23	30	53
		43%	57%	100%
	Predictability <= .004788	5	7	12
		42%	58%	100%

A.4

	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	13	2.72
	Predictability <= .004788	4	.23
	Total	17	2.14
OWNER	Predictability > .004788	23	3.56
	Predictability <= .004788	5	.27
	Total	28	2.97
Total	Predictability > .004788	36	3.26
	Predictability <= .004788	9	.25

	Total	45	2.66

A5 Other

		Occurrence A5		
		YES	NO	Total
CONTRACTOR	Predictability > .004788	6	42	48
		13%	88%	100%
	Predictability <= .004788	8	14	22
		36%	64%	100%
OWNER	Predictability > .004788	6	47	53
		11%	89%	100%
	Predictability <= .004788	2	10	12
		17%	83%	100%

A.5

	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	6	3.84
	Predictability <= .004788	8	.66
	Total	14	2.02
OWNER	Predictability > .004788	6	2.08
	Predictability <= .004788	2	.05
	Total	8	1.57
Total	Predictability > .004788	12	2.96
	Predictability <= .004788	10	.54
	Total	22	1.86

B6 HSSE Issues

		Occurrence B6		
		YES	NO	Total
CONTRACTOR	Predictability > .004788	1	47	48
		2%	98%	100%
	Predictability <= .004788	1	21	22
		5%	95%	100%
OWNER	Predictability > .004788	9	44	53
		17%	83%	100%
	Predictability <= .004788	3	9	12
		25%	75%	100%

B.6

	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	1	.38
	Total	1	.38
OWNER	Predictability > .004788	9	2.06
	Predictability <= .004788	3	.33
	Total	12	1.63
Total	Predictability > .004788	10	1.89
	Predictability <= .004788	3	.33

	Total	13	1.53

B8 Permitting Issues

		Occurrence B8		
		YES	NO	Total
CONTRACTOR	Predictability > .004788	4	44	48
		8%	92%	100%
	Predictability <= .004788	3	19	22
		14%	86%	100%
OWNER	Predictability > .004788	1	52	53
		2%	98%	100%
	Predictability <= .004788	2	10	12
		17%	83%	100%

B.8	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	4	3.82
	Predictability <= .004788	3	.16
	Total	7	2.25
OWNER	Predictability <= .004788	2	.33
	Total	2	.33
Total	Predictability > .004788	4	3.82
	Predictability <= .004788	5	.23
	Total	9	1.83

C10 Design/Engineering Errors/Omission

		Occurrence C10		
		YES	NO	Total
CONTRACTOR	Predictability > .004788	20	28	48
		42%	58%	100%
	Predictability <= .004788	4	18	22
		18%	82%	100%
OWNER	Predictability > .004788	26	27	53
		49%	51%	100%
	Predictability <= .004788	10	2	12
		83%	17%	100%

C.10	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	20	1.59
	Predictability <= .004788	4	.12
	Total	24	1.34

OWNER	Predictability > .004788	26	1.79
	Predictability <= .004788	10	.38
	Total	36	1.40
Total	Predictability > .004788	46	1.70
	Predictability <= .004788	14	.31
	Total	60	1.38

<u>C11 Engineering Productivity</u>

		Occurrence C11		
		YES	NO	Total
CONTRACTOR	Predictability > .004788	11	37	48
		23%	77%	100%
	Predictability <= .004788	6	16	22
		27%	73%	100%
OWNER	Predictability > .004788	13	40	53
		25%	75%	100%
	Predictability <= .004788	5	7	12
		42%	58%	100%

C.11	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	11	2.59
	Predictability <= .004788	6	.41
	Total	17	1.82
OWNER	Predictability > .004788	13	1.72
	Predictability <= .004788	5	.28
	Total	18	1.32
Total	Predictability > .004788	24	2.12
	Predictability <= .004788	11	.35
	Total	35	1.56

<u>D13 Construction Productivity</u>

		Occurrence D13		
		YES	NO	Total
CONTRACTOR	Predictability > .004788	21	27	48
		44%	56%	100%
	Predictability <= .004788	10	12	22
		45%	55%	100%
OWNER	Predictability > .004788	29	24	53
		55%	45%	100%
	Predictability <= .004788	6	6	12
		50%	50%	100%

D.13

	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	21	2.00
	Predictability <= .004788	10	.43
	Total	31	1.49
OWNER	Predictability > .004788	29	2.05
	Predictability <= .004788	6	.29
	Total	35	1.75
Total	Predictability > .004788	50	2.03
	Predictability <= .004788	16	.38
	Total	66	1.63

D14 Construction Errors/Omissions

		Occurrence D14		
		YES	NO	Total
CONTRACTOR	Predictability > .004788	3	45	48
		6%	94%	100%
	Predictability <= .004788	3	19	22
		14%	86%	100%
OWNER	Predictability > .004788	7	46	53
		13%	87%	100%
	Predictability <= .004788	1	11	12
		8%	92%	100%

D.14

	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	3	1.08
	Predictability <= .004788	3	.08
	Total	6	.58
OWNER	Predictability > .004788	7	1.42
	Predictability <= .004788	1	.25
	Total	8	1.27
Total	Predictability > .004788	10	1.32
	Predictability <= .004788	4	.13
	Total	14	.98

D15 Construction Equipment Issues

		Occurrence D15 YES	NO	Total
CONTRACTOR	Predictability > .004788	4	44	48
		8%	92%	100%
	Predictability <= .004788	1	21	22
		5%	95%	100%
OWNER	Predictability > .004788	13	40	53
		25%	75%	100%
	Predictability <= .004788	1	11	12
		8%	92%	100%

D.15	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	4	1.56
	Predictability <= .004788	1	.01
	Total	5	1.25
OWNER	Predictability > .004788	13	3.77
	Predictability <= .004788	1	.14
	Total	14	3.51
Total	Predictability > .004788	17	3.25
	Predictability <= .004788	2	.08
	Total	19	2.92

D16 Infrastructure, Site or Utilities Issues

		Occurrence D16 YES	NO	Total
CONTRACTOR	Predictability > .004788	5	43	48
		10%	90%	100%
	Predictability <= .004788	1	21	22
		5%	95%	100%
OWNER	Predictability > .004788	11	42	53
		21%	79%	100%
	Predictability <= .004788	1	11	12
		8%	92%	100%

D.16	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	5	1.79
	Total	5	1.79
OWNER	Predictability > .004788	11	2.74
	Predictability <= .004788	1	.87

	Total	12	2.58
Total	Predictability > .004788	16	2.44
	Predictability <= .004788	1	.87
	Total	17	2.35

<u>D17 Others</u>

		Occurrence D17		
		YES	NO	Total
CONTRACTOR	Predictability > .004788	7	41	48
		15%	85%	100%
	Predictability <= .004788	1	21	22
		5%	95%	100%
OWNER	Predictability > .004788	7	46	53
		13%	87%	100%
	Predictability <= .004788	1	11	12
		8%	92%	100%

D.17	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	7	1.40
	Predictability <= .004788	1	.24
	Total	8	1.25
OWNER	Predictability > .004788	7	2.85
	Predictability <= .004788	1	.13
	Total	8	2.51
Total	Predictability > .004788	14	2.12
	Predictability <= .004788	2	.19
	Total	16	1.88

<u>E18 Startup/Commissioning issues</u>

		Occurrence E18		
		YES	NO	Total
CONTRACTOR	Predictability > .004788	9	39	48
		19%	81%	100%
	Predictability <= .004788	12	10	22
		55%	45%	100%
OWNER	Predictability > .004788	12	41	53
		23%	77%	100%
	Predictability <= .004788	2	10	12
		17%	83%	100%

E.18

	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	9	1.96
	Predictability <= .004788	12	.43
	Total	21	1.08
OWNER	Predictability > .004788	12	1.35
	Predictability <= .004788	2	.58
	Total	14	1.24
Total	Predictability > .004788	21	1.61
	Predictability <= .004788	14	.45
	Total	35	1.15

F19 Cost Estimating Issues

		Occurrence F19		
		YES	NO	Total
CONTRACTOR	Predictability > .004788	16	32	48
		33%	67%	100%
	Predictability <= .004788	5	17	22
		23%	77%	100%
OWNER	Predictability > .004788	9	44	53
		17%	83%	100%
	Predictability <= .004788	1	11	12
		8%	92%	100%

F.19

	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	16	1.48
	Predictability <= .004788	5	.24
	Total	21	1.19
OWNER	Predictability > .004788	9	2.29
	Predictability <= .004788	1	.17
	Total	10	2.07
Total	Predictability > .004788	25	1.77
	Predictability <= .004788	6	.23
	Total	31	1.47

F20 Scheduling Issues

		Occurrence F20 YES	NO	Total
CONTRACTOR	Predictability > .004788	10	38	48
		21%	79%	100%
	Predictability <= .004788	1	21	22
		5%	95%	100%
OWNER	Predictability > .004788	10	43	53
		19%	81%	100%
	Predictability <= .004788	1	11	12
		8%	92%	100%

F.20	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	10	1.67
	Predictability <= .004788	1	.05
	Total	11	1.52
OWNER	Predictability > .004788	10	2.39
	Total	10	2.39
Total	Predictability > .004788	20	2.03
	Predictability <= .004788	1	.05
	Total	21	1.93

F21 Cost Forecasting Issues

		Occurrence F21 YES	NO	Total
CONTRACTOR	Predictability > .004788	7	41	48
		15%	85%	100%
	Predictability <= .004788	1	21	22
		5%	95%	100%
OWNER	Predictability > .004788	3	50	53
		6%	94%	100%
	Predictability <= .004788	1	11	12
		8%	92%	100%

F.21	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	7	1.34
	Predictability <= .004788	1	.38
	Total	8	1.22
OWNER	Predictability > .004788	3	1.54
	Total	3	1.54

Total	Predictability > .004788	10	1.40
	Predictability <= .004788	1	.38
	Total	11	1.31

F22 Project Management Issues

		Occurrence F22		
		YES	NO	Total
CONTRACTOR	Predictability > .004788	3	45	48
		6%	94%	100%
	Predictability <= .004788	1	21	22
		5%	95%	100%
OWNER	Predictability > .004788	9	44	53
		17%	83%	100%
	Predictability <= .004788	1	11	12
		8%	92%	100%

F.22	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	3	2.45
	Predictability <= .004788	1	.06
	Total	4	1.85
OWNER	Predictability > .004788	9	3.15
	Predictability <= .004788	1	.25
	Total	10	2.86
Total	Predictability > .004788	12	2.98
	Predictability <= .004788	2	.16
	Total	14	2.57

F23 Project Team Integration Issues (Data/information exchange, communications, teamwork)

		Occurrence F23		
		YES	NO	Total
CONTRACTOR	Predictability > .004788	5	43	48
		10%	90%	100%
	Predictability <= .004788	1	21	22
		5%	95%	100%
OWNER	Predictability > .004788	3	50	53
		6%	94%	100%
	Predictability <= .004788	1	11	12
		8%	92%	100%

F.23

	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	5	2.29
	Predictability <= .004788	1	.02
	Total	6	1.91
OWNER	Predictability > .004788	3	4.55
	Total	3	4.55
Total	Predictability > .004788	8	3.14
	Predictability <= .004788	1	.02
	Total	9	2.79

G25 Supplier/Subcontractor Issues

		Occurrence G25		
		YES	NO	Total
CONTRACTOR	Predictability > .004788	17	31	48
		35%	65%	100%
	Predictability <= .004788	11	11	22
		50%	50%	100%
OWNER	Predictability > .004788	13	40	53
		25%	75%	100%
	Predictability <= .004788	4	8	12
		33%	67%	100%

G.25

	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	17	1.57
	Predictability <= .004788	11	.43
	Total	28	1.12
OWNER	Predictability > .004788	13	1.80
	Predictability <= .004788	4	.22
	Total	17	1.43
Total	Predictability > .004788	30	1.67
	Predictability <= .004788	15	.37
	Total	45	1.24

G26 Market Supply Issues

		Occurrence G26 YES	NO	Total
CONTRACTOR	Predictability > .004788	7	41	48
		15%	85%	100%
	Predictability <= .004788	1	21	22
		5%	95%	100%
OWNER	Predictability > .004788	4	49	53
		8%	92%	100%
	Predictability <= .004788	3	9	12
		25%	75%	100%

G.26	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	7	.73
	Total	7	.73
OWNER	Predictability > .004788	4	1.26
	Predictability <= .004788	3	.29
	Total	7	.84
Total	Predictability > .004788	11	.92
	Predictability <= .004788	3	.29
	Total	14	.79

G27 Logistics Issues

		Occurrence G27 YES	NO	Total
CONTRACTOR	Predictability > .004788	1	47	48
		2%	98%	100%
	Predictability <= .004788	1	21	22
		5%	95%	100%
OWNER	Predictability > .004788	11	42	53
		21%	79%	100%
	Predictability <= .004788	1	11	12
		8%	92%	100%

G.27	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	1	1.81
	Predictability <= .004788	1	.14
	Total	2	.98
OWNER	Predictability > .004788	11	2.88
	Predictability <= .004788	1	.19

		N	Mean
	Total	12	2.65
Total	Predictability > .004788	12	2.79
	Predictability <= .004788	2	.17
	Total	14	2.41

G28 Procurement Process Issues

		Occurrence G28		
		YES	NO	Total
CONTRACTOR	Predictability > .004788	8	40	48
		17%	83%	100%
	Predictability <= .004788	1	21	22
		5%	95%	100%
OWNER	Predictability > .004788	7	46	53
		13%	87%	100%
	Predictability <= .004788	1	11	12
		8%	92%	100%

G.28	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	8	1.83
	Predictability <= .004788	1	.04
	Total	9	1.63
OWNER	Predictability > .004788	7	3.56
	Total	7	3.56
Total	Predictability > .004788	15	2.64
	Predictability <= .004788	1	.04
	Total	16	2.47

H30 Foreign exchange

		Occurrence H30		
		YES	NO	Total
CONTRACTOR	Predictability > .004788	4	44	48
		8%	92%	100%
	Predictability <= .004788	1	21	22
		5%	95%	100%
OWNER	Predictability > .004788	3	50	53
		6%	94%	100%
	Predictability <= .004788	1	11	12
		8%	92%	100%

H.30

	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	4	1.68
	Total	4	1.68
OWNER	Predictability > .004788	3	2.61
	Total	3	2.61
Total	Predictability > .004788	7	2.08
	Total	7	2.08

J36 Acts of God: flood/earthquake/hurricane

		Occurrence J36		
		YES	NO	Total
CONTRACTOR	Predictability > .004788	8	40	48
		17%	83%	100%
	Predictability <= .004788	1	21	22
		5%	95%	100%
OWNER	Predictability > .004788	2	51	53
		4%	96%	100%
	Predictability <= .004788	2	10	12
		17%	83%	100%

J.36

	Admissible Predictability	N	Mean
CONTRACTOR	Predictability > .004788	8	2.69
	Predictability <= .004788	1	.07
	Total	9	2.40
OWNER	Predictability > .004788	2	.34
	Predictability <= .004788	2	.20
	Total	4	.27
Total	Predictability > .004788	10	2.22
	Predictability <= .004788	3	.16
	Total	13	1.74

C.3 Hypothesis 3: Influencing Factors

C.3.1 Tests of relationship at Variable Level (Predictability by Project Characteristics)

Variable Q1.1 Role

Predictability * Role

			Role		
			CONTRACTOR	OWNER	Total
Quarter	(Q4) Predictability > .0588	Count	13_a	21_a	34
		% within Quarter	38.2%	61.8%	100.0%
	(Q3) Predictability > .0183 & <= .0588	Count	16_a	17_a	33
		% within Quarter	48.5%	51.5%	100.0%
	(Q2) Predictability >.0048 & <= .0183	Count	19_a	15_a	34
		% within Quarter	55.9%	44.1%	100.0%
	(Q1) Predictability <= .0048	Count	22_a	12_a	34
		% within Quarter	64.7%	35.3%	100.0%
Total		Count	70	65	135
		% within Quarter	51.9%	48.1%	100.0%

Each subscript letter denotes a subset of Role categories whose column proportions do not differ significantly from each other at the .05 level.

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Ordinal by Ordinal	Kendall's tau-b	-.178	.076	2.331	.020
	Kendall's tau-c	-.218	.093	2.331	.020
N of Valid Cases		135			

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

Variable Q1.3 Site Location

		P.1.3 Location		
		Inside of US	Outside of US	Total
Quarter-Group	(Q4) Predictability > .0588	20	14	34
	(Q3) Predictability > .0183 & <= .0588	26	7	33
	(Q2) Predictability >.0048 & <= .0183	28	6	34
	(Q1) Predictability <= .0048	28	6	34
Total		102	33	135

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Ordinal by Ordinal	Kendall's tau-b	-.177	.079	2.184	.029
	Kendall's tau-c	-.186	.085	2.184	.029
N of Valid Cases		135			

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

Variable Q1.4 Third Part Funding

		P.1.4 Funding				Total
		Yes	No	Partial	Unknown	
Quarter-Group	(Q4) Predictability > .0588	0	2	27	5	34
	(Q3) Predictability > .0183 & <= .0588	2	1	26	4	33
	(Q2) Predictability >.0048 & <= .0183	1	2	27	4	34
	(Q1) Predictability <= .0048	11	1	19	3	34
Total		14	6	99	16	135

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Ordinal by Ordinal	Kendall's tau-b	-.215	.077	2.691	.007
	Kendall's tau-c	-.164	.061	2.691	.007
N of Valid Cases		135			

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

Variable Q1.6 Year of Completion

		P.1.6 Completion year		Total
		Before 2010	After 2010	
Quarter-Group	(Q4) Predictability > .0588	27	7	34
	(Q3) Predictability > .0183 & <= .0588	23	10	33
	(Q2) Predictability >.0048 & <= .0183	20	14	34
	(Q1) Predictability <= .0048	18	16	34
Total		88	47	135

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Ordinal by Ordinal	Kendall's tau-b	-.194	.075	-2.568	.010
	Kendall's tau-c	-.226	.088	-2.568	.010
N of Valid Cases		135			

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

Variable Q1.14 Project Nature

		P.1.14 Project nature			Total
		Green	Brown	Renovation	
Quarter-Group	(Q4) Predictability > .0588	5	6	23	34
	(Q3) Predictability > .0183 & <= .0588	4	8	21	33
	(Q2) Predictability >.0048 & <= .0183	6	6	22	34
	(Q1) Predictability <= .0048	8	12	14	34
Total		23	32	80	135

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Ordinal by Ordinal	Kendall's tau-b	-.150	.074	2.016	.044
	Kendall's tau-c	-.147	.073	2.016	.044
N of Valid Cases		135			

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

Variable Q1.15 Legal Constraints

		P.1.15 Legal constraints			Total
		Many	Few	None	
Quarter-Group	(Q4) Predictability > .0588	23	5	5	33
	(Q3) Predictability > .0183 & <= .0588	17	2	14	33
	(Q2) Predictability >.0048 & <= .0183	12	4	18	34
	(Q1) Predictability <= .0048	18	7	9	34
Total		70	18	46	134

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Ordinal by Ordinal	Kendall's tau-b	-.114	.070	-1.627	.104
	Kendall's tau-c	-.114	.070	-1.627	.104
N of Valid Cases		135			

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

Variable Q1.17 Incentives

		P.1.17 Incentives		Total
		Incentives	No Incentives	
Quarter-Group	(Q4) Predictability > .0588	5	29	34
	(Q3) Predictability > .0183 & <= .0588	12	21	33
	(Q2) Predictability >.0048 & <= .0183	14	20	34
	(Q1) Predictability <= .0048	20	14	34
Total		51	84	135

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Ordinal by Ordinal	Kendall's tau-b	.290	.071	4.034	.000
	Kendall's tau-c	.344	.085	4.034	.000
N of Valid Cases		135			

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

Variable Project Driver

		Project Driver			Total
		Both & Other	Cost	Schedule	
Quarter-Group	(Q4) Predictability > .0588	13	6	15	34
	(Q3) Predictability > .0183 & <= .0588	12	8	13	33
	(Q2) Predictability >.0048 & <= .0183	9	5	20	34
	(Q1) Predictability <= .0048	6	5	23	34
Total		40	24	71	135

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Ordinal by Ordinal	Kendall's tau-b	-.181	.073	-2.495	.013
	Kendall's tau-c	-.183	.073	-2.495	.013
N of Valid Cases		135			

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

C.3.2 Tests of relationship at Category Level (Predictability by Project Characteristics)

Variable Q1.2 Affiliation /Category: Public

P.1.2 Affiliation			Role		Total
			CONTRACTOR	OWNER	
Public	Quarter-Group	(Q4) Predictability > .0588	2	12	14
		(Q3) Predictability > .0183 & <= .0588	8	10	18
		(Q2) Predictability >.0048 & <= .0183	9	10	19
		(Q1) Predictability <= .0048	9	6	15
	Total		28	38	66

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Ordinal by Ordinal	Kendall's tau-b	-.265	.103	2.558	.011
	Kendall's tau-c	-.320	.125	2.558	.011
N of Valid Cases		66			

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

Variable Q1.7 Project Duration /Category: 80 to 120 weeks and 120 to 160 weeks

Q1.7 Project Duration (Weeks)			Role		Total
			CONTRACTOR	OWNER	
120 -160	Quarter-Group	(Q4) Predictability > .0588	0	3	3
		(Q3) Predictability > .0183 & <= .0588	2	3	5
		(Q2) Predictability >.0048 & <= .0183	2	4	6
		(Q1) Predictability <= .0048	6	2	8
	Total		10	12	22
80 -120	Quarter-Group	(Q4) Predictability > .0588	1	6	7
		(Q3) Predictability > .0183 & <= .0588	4	1	5
		(Q2) Predictability >.0048 & <= .0183	1	0	1
		(Q1) Predictability <= .0048	6	3	9
	Total		12	10	22

Symmetric Measures

Q1.7 Project Duration (Weeks)			Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
120 – 160	Ordinal by Ordinal	Kendall's tau-b	.428	.159	2.670	.008
		Kendall's tau-c	.512	.192	2.670	.008
	N of Valid Cases		22			
80 - 120	Ordinal by Ordinal	Kendall's tau-b	.385	.188	2.038	.042
		Kendall's tau-c	.446	.219	2.038	.042
	N of Valid Cases		22			

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

Variable Q1.7 Project Duration /Category: > 80 weeks

Q1.7 Project Duration (Weeks)			Role		Total
			CONTRACTOR	OWNER	
> 80 weeks	Quarter-Group	(Q4) Predictability > .0588	7	14	21
		(Q3) Predictability > .0183 & <= .0588	10	9	19
		(Q2) Predictability >.0048 & <= .0183	8	7	15
		(Q1) Predictability <= .0048	17	5	22
	Total		42	35	77

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Ordinal by Ordinal	Kendall's tau-b	-.292	.096	3.054	.002
	Kendall's tau-c	-.356	.116	3.054	.002
N of Valid Cases		77			

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

Variable Q1.8 Technology /Category: Familiar

P.1.8 Tech-familiarity			Role: CONTRACTOR	Role: OWNER	Total
Familiar	Quarter-Group	(Q4) Predictability > .0588	9	19	28
		(Q3) Predictability > .0183 & <= .0588	15	11	26
		(Q2) Predictability >.0048 & <= .0183	16	11	27
		(Q1) Predictability <= .0048	21	8	29
	Total		61	49	110

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Ordinal by Ordinal	Kendall's tau-b	-.256	.082	3.114	.002
	Kendall's tau-c	-.312	.100	3.114	.002
N of Valid Cases		110			

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

Variable Q1.10 Office Structure /Category: Local

P.1.10 Office			Role: CONTRACTOR	Role: OWNER	Total
Local	Quarter-Group	(Q4) Predictability > .0588	4	19	23
		(Q3) Predictability > .0183 & <= .0588	7	9	16
		(Q2) Predictability >.0048 & <= .0183	8	3	11
		(Q1) Predictability <= .0048	3	4	7
	Total		22	35	57

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Ordinal by Ordinal	Kendall's tau-b	-.325	.112	2.878	.004
	Kendall's tau-c	-.376	.130	2.878	.004
N of Valid Cases		57			

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

Variable Q1.11 Project Cost /Category: > $100 MM

P.1.11 Project Final Cost			Role: CONTRACTOR	Role: OWNER	Total
>$100MM	Quarter-Group	(Q4) Predictability > .0588	3	11	14
		(Q3) Predictability > .0183 & <= .0588	6	8	14
		(Q2) Predictability >.0048 & <= .0183	6	6	12
		(Q1) Predictability <= .0048	12	1	13
	Total		27	26	53

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Ordinal by Ordinal	Kendall's tau-b	.450	.100	4.521	.000
	Kendall's tau-c	.551	.122	4.521	.000
N of Valid Cases		53			

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.

Variable Q1.16 Payment Strategy /Category: Lump Sum

P.1.16 Payment Method			Role: CONTRACTOR	Role: OWNER	Total
Lump Sum	Quarter-Group	(Q4) Predictability > .0588	3	17	20
		(Q3) Predictability > .0183 & <= .0588	9	8	17
		(Q2) Predictability >.0048 & <= .0183	9	2	11
		(Q1) Predictability <= .0048	17	7	24
	Total		38	34	72

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Ordinal by Ordinal	Kendall's tau-b	-.410	.095	4.324	.000
	Kendall's tau-c	-.495	.115	4.324	.000
N of Valid Cases		72			

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.