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Improving Early Prediction of Cost and Time Outcomes by the Predictability Index

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In Memory of My Father

1 ACKNOWLEDGMENTS

I would like to dedicate this effort to my family who supported me in all stages of my life and my studies and their continuous support and motivation throughout this journey was the source of power that enabled me to reach here.

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3 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. Accurate forecasting of an ongoing project cost is a major issue in project monitoring. This study proposes to evaluate cost and schedule performance based on the early and accurate prediction of final outcomes, as opposed to the prevalent and reactive evaluation of final cost and schedule deviations at completion. Getting to know early in the delivery process the actual outcomes of a project enables project and corporate managers to undertake informed and proactive actions in a timely manner. The ability to timely forecast accurate project outcomes is fundamental in an industry marked by endemic cost and schedule deviations. Indeed, owners and contractors alike make key strategic decisions about individual projects and capital investment programs alike based on forecasted values. As a departure from current cost and schedule assessments solely based on deviations at completion, this study introduces the Predictability Index, a novel performance metric that also considers the project team's ability to timely predict outcomes at completion. This study conceptually explains and defines the index and, based on the statistical analysis of retrospective data from 135 completed projects representing $29 billion in total installed costs, identifies threshold values of predictability performance. Also, actual case studies are discussed in order to illustrate the tangible benefits associated with the assessment of predictability performance to the project delivery process. Complementary, lessons learned and observations collected from the adoption and assessment of predictability by industry organizations are also discussed. A significant cultural shift within an organization is necessary for project teams to focus on predictability performance.

4 INTRODUCTION

4.1 STATEMENT OF THE PROBLEM:

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. Many industry leaders argue that project teams simply lack the ability to make accurate predictions on cost and schedule outcomes at completion, leading them to withhold corrective actions until stronger verification or additional indicators that substantiate outcome predictions are available. This lack of confidence in outcome predictions, or the suspicion of significant inaccuracies, undermines the ability to proactively adopt corrective actions in a timely manner. In an industry characterized by cost and schedule deviations at completion, profitability losses invariably result when such deviations are not timely ascertained (Mulva and Dai 2012). 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).

4.2 OBJECTIVES OF THE STUDY:

As a departure from current cost and schedule assessments solely based on deviations at completion, this study introduces the Predictability Index, a novel performance metric that also measures the project team's ability to predict outcomes in a timely manner. Throughout the article, predictability is defined as the ability to accurately forecast the actual outcomes at completion early, as opposed to late, in the project delivery process.

Indeed, the ability to timely forecast accurate project outcomes is fundamental for an industry marked by endemic cost and schedule deviations on simultaneous project endeavors executed within complex portfolios of capital investment (Flyvbjerg et al. 2002; Kimand Reinschmidt 2011; Orberlender and Trost 2011; Grau et al. 2014). Too frequently, the order of magnitude of such deviations, either positive or negative, is "not only by a few percent but by several factors" (Flyvbjerg 2006). Such inability to contain cost and schedule outcomes highlights the importance of early and accurate predictions. Predictable and accurate cash-flow balances are necessary for accountable budgeting practices (Liu et al. 2013). In reality, the expected or forecasted cost and schedule performance on simultaneous projects are considered altogether by upper management in order to properly allocate financial, equipment, and human resources, and reduce risk throughout the portfolio of projects (Oberlender and Trost 2001). An organizational management perspective is indeed required to satisfy the multiproject environment in which the capital industry operates (Payne 1995).

To date, the cost and schedule performance by a project team is still solely assessed based on the deviation error between the corresponding baseline or estimated outcome and the actual outcome at completion. Specifically, the project team's cost performance is evaluated based on the deviation between baseline costs (e.g., authorized budget for owners or contract value for contractors) and total installed costs, while its schedule performance is evaluated based on the deviation between the expected or baseline completion time and the actual completion time. In this type of outcome-centric performance assessment, project managers express that the prediction of a positive deviation at completion (i.e., overrun) raises concern, scrutiny, and suspicion from the home office, while the prediction of a negative deviation at completion (i.e., underrun) frequently results in attitudes of trust, satisfaction, and relief, and hence in loose mechanisms of control (Back and Grau 2013a). Due to such types of behaviors, outcome-centric assessments tend to undermine transparency, and with that hinder profitability, disregard the chance for an early disclosure of actual outcomes, and, as explained later in this text, negatively affect cash flow balances.

Overall, current cost and schedule performance assessments do not incentivize the early disclosure of cost and schedule outcomes, and inform little or nothing on how early deviations were identified. As such, the ability to make reliable, timely, and well-informed decisions to effectively support projects, capital investment programs, and key stakeholder organizations alike is undermined. To overcome such fundamental limitations, we have investigated a novel cost and schedule performance metric, the Predictability Index, which accounts for both the timely and accurate disclosure of actual outcomes at completion, as opposed to current performance assessments solely based on final deviations. In different words, the Predictability Index also measures the ability of a project team to forecast reliable outcome performance predictions early, as opposed to late, in the project timeline.

4.3 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.

4.4 ENDEMIC COST AND SCHEDUALE DEVIATION:

Throughout recent years, there have been numerous reports globally on pervasive cost and schedule deviations (oftentimes overruns) on capital projects (e.g., Assaf & Al-Hejji, 2006; Back & Grau, 2013a; Flyvbjerg et al., 2002; Jaseleskis & Ashley, 1991; Mott MacDonald, 2002; Mulva & Dai, 2012). The construction industry maybe more than others has been plagued with various risks that result in cost and time overruns, poor project performance, and even project failures (An, Baker, & Zeng, 2005). These deviations are not limited to one industry sector but have been evident in residential, office, industrial, infrastructure, and other project sectors (e.g., Flyvbjerg et al., 2002). Such deviations show that a more effective mechanism needs to be in place to ascertain appropriate project progress according to plans and objectives. The lack of satisfactory project performance itself indicates a need for better monitoring and control. 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).

4.5 LACK OF PREDICTIBILITY:

Forecasting is a major and important project controls function. Project managers go beyond finding the status of the project, and look at the possible future outcomes of the project. Such forecasting efforts are made to support timely and effective decision making.

As indicated by recent research (Grau & Back, 2015b), currently projects are not predictable as to what their performance outcome will be in terms of cost and time.

These deviations, whether positive or negative, are frequently "not only by a few percent but by several factors" (Flyvbjerg, 2006). These deviations highlight the importance of early and accurate predictions. The lack of project predictability has many negative implications such that organizations can't proactively optimize resources (i.e., money) across projects to maximize profitability (Mulva & Dai, 2012). Contrary to intuition, Mulva and Dai (2012) quantitatively showed how both cost underruns and overruns contribute to profitability losses. Their study was based on a statistical analysis of historical data from a 16-year time span. The effects of net present value (NPV) on actual cash-flow balances was investigated for an average project and also for two scenarios. For instance, if project stakeholders know earlier that a project cost will be under what was originally estimated they can reallocate the extra funds to other profitable endeavors. Otherwise, their capital will be allocated to the current project, and potential profitability losses will ensue due to the unused spare budget. On the other hand, early disclosure of project cost overruns doesn't warranty that these overruns will be reduced or eliminated; however, the disclosure of such overruns ensures increase in monitoring, controls, and scrutiny of the project to suppress further overruns (Back & Grau, 2013a; Callahan, Stetz, & Brooks, 2007). Closer monitoring of project status is needed for better insight into the projects and better predictability of resource utilization and final project performance.

Currently, projects performance is assessed based on a single point deviation between actual outcome and the estimated or baseline outcome. For instance, cost deviations are assessed based on the deviation between baseline cost and total installed cost, while time performance is assessed based on the deviation between baseline schedule and total installed time.

This type of outcome-centric performance assessment results in negative assessment when overruns are reported at completion and positive reactions when underruns are reported at completion. Due to this behavior, outcome-centric assessment of project performance harms transparency and hinders the early disclosure of final project outcome; this will negatively affect project controls as there is less information available late into the project lifecycle. Currently, project team members are awarded or punished based on final project performance against the baseline plan. This type of incentives does not award or punish project stakeholders based on early revelation of critical project information. This trend and lack of timely information delivery prevents well-informed decisions and effective control of projects.

5 LITERATURE REVIEW

5.1 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.

5.2 Forecasting at Completion:

Estimates can be generated using either deterministic or stochastic approaches. Most project control techniques are based on deterministic approaches because of its inherent simplicity, even though probabilistic approaches have been gaining acceptance over the last two decades. Deterministic approaches have an inherent limitation in that they do not account for the varying impact that events and trends may have on a project.

The deterministic approach estimates final schedule values and outcomes based on point estimates of most likely values, while, probabilistic methods consider variability in duration values when estimating project schedule. As an example of a probabilistic method, Kim and Reinschmidt (2009) use Bayesian inference and the beta distribution to provide confidence bounds on predictions and determine the range of potential outcomes and the probability of success. Furthermore, Kim and Reinschmidt (2010) use Kalman filters and the EVM to make probabilistic forecasts of project duration. In spite of the superiority of probabilistic methods in depicting the variable behavior of projects (Crandall & Woolery, 1982), deterministic methods are more frequently used because they simpler to apply (Barraza et al., 2004). Line-of-balance (LOB) scheduling technique is one of several distinctly important scheduling techniques. LOB scheduling is well suited to linear and repetitive projects, as it is a visual technique where inefficiencies, production rates, and clashes can be found quickly from charts and diagrams. 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.

5.3 EVM (Earned Value Method)

The Earned Value Method (EVM) is a cost estimating and scheduling technique that is widely used for periodic monitoring of actual expenditures and physical scope accomplishment and, accordingly, for generating period-by-period progress reports (El-Omari & Moselhi, 2011). 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). The Project Management Institute (PMI, 2005) claims that when correctly applied, EVM provides an early warning of performance anomalies.

EVM originally coined "Cost/Schedule Control Systems Criteria (C/SCSC)," was developed by the Department of Defense in the 1960s to monitor and control large flexible-priced defense projects (DoD, 1967; Christensen, 1998; Kim, Wells, & Duffey, 2003; Moselhi, Li, & Alkass, 2004; Rozenes et al., 2006). Its appeal is owed to its simplicity, integration of time and cost performance measures, and ability to provide early warning signs on cost performance (overrun or underrun) and schedule performance (ahead or behind) (Vanhoucke, 2009). EVM indicators have been found to be reliable as early as 15% into a project (Fleming & Koppelman, 2000). Better planning and allocation of resources early in the project may be part of this reliability.

Succinctly, EVM is based on the representation of three measures: first, the budgeted cost for work scheduled (BCWS)—also called planned value (PV); second, the actual cost for work performed (ACWP)—also called actual cost (AC); and finally, the budgeted cost for work performed (BCWP) or earned value (EV). EVM integrates cost, schedule, scope, and technical performance under the same framework, and it provides metrics that allow managers to detect cost or schedule deviations (Fleming & Koppleman, 2000; Kerzner, 2003; Kim et al., 2003; Naeni, Shadrokh, & Salehipour, 2011; Plaza & Turetken, 2009; Warhoe, 2004).

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.

5.4 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.

5.5 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.

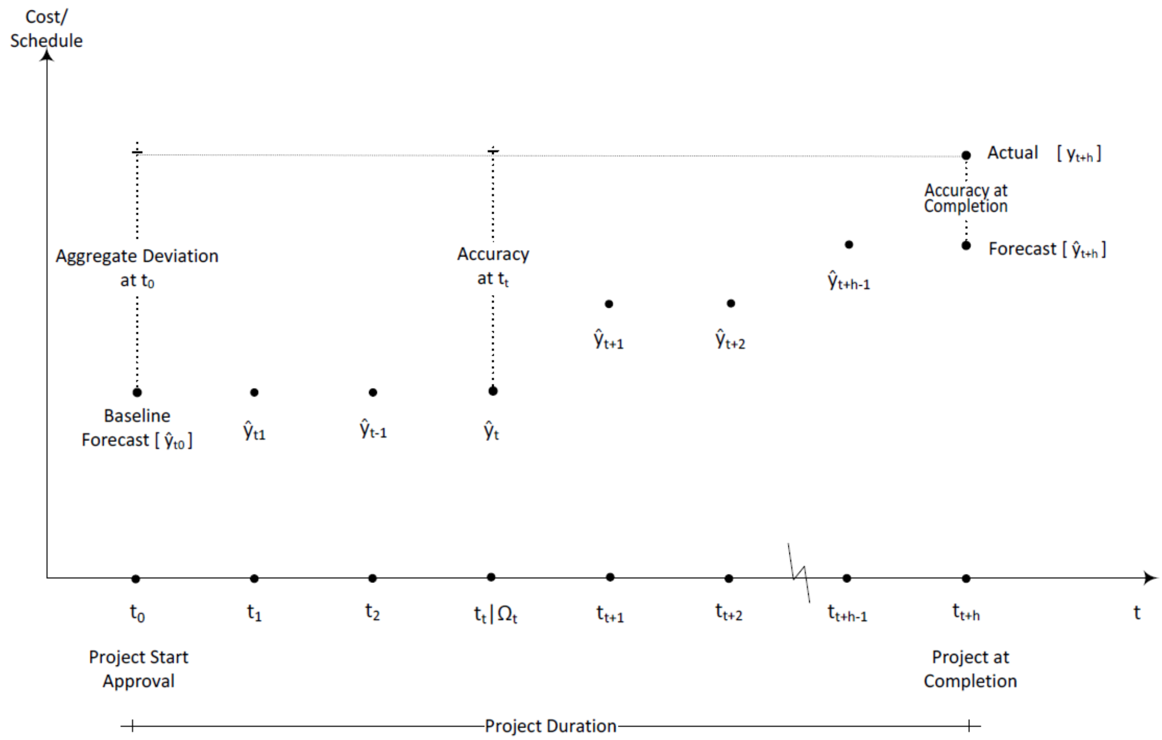


Figure 1. Forecasting accuracy of outcomes at completion.

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 1). Nevertheless, these measures are indicators that inform little or nothing about the efficiency of the predictability and how early adverse aggregated deviations were detected.

5.6 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 2).

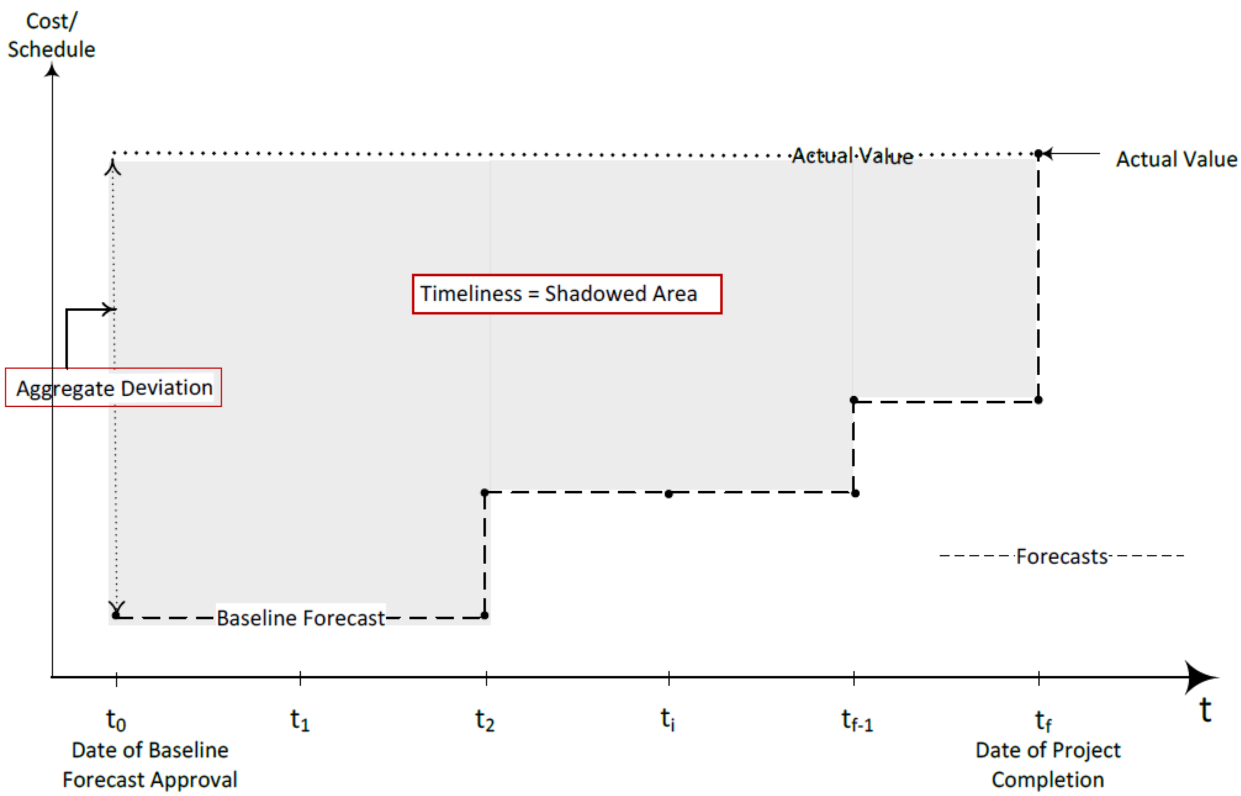


Figure 2. Accuracy and timeliness of construction forecasting.

When choosing a forecasting method, consideration must be given to data availability, complexity of the estimating model, data points available, existing relationships, and also expectations (Diekmann, 1983).

5.7 Categories of Information About Cost and Time

Any estimate, either cost or time, needs to consider three categories of information (Molenaar, 2005). Such categories are: 1) the known and quantifiable costs or time values; 2) the known but not quantifiable values (known/unknowns); and 3) the unknown and unrecognized values.

As the project progresses the known/unknowns and unknown/unknowns can be recognized and quantified. Thus, as more pieces of information unveil and are gathered and processed, an estimate becomes more accurate. Such unveiling of the cost and time performance naturally happens as a project advances and nears completion, to the extent that a number of projects suffer late unpleasant surprises, in which cost and/or schedule deviations are unveiled without time for remediation actions (see Figure 3).

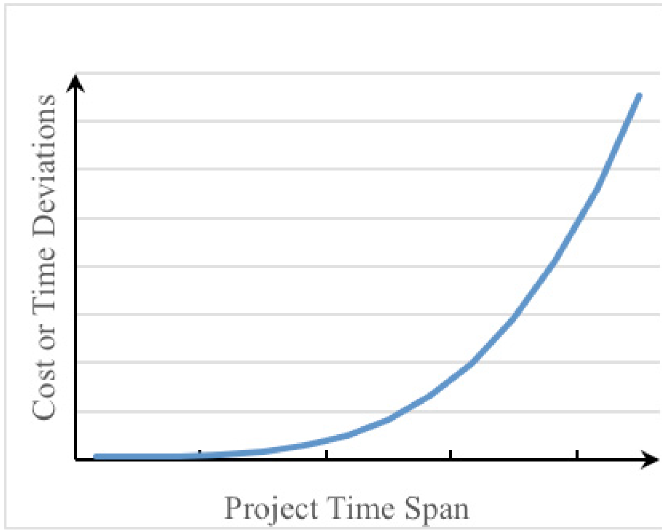


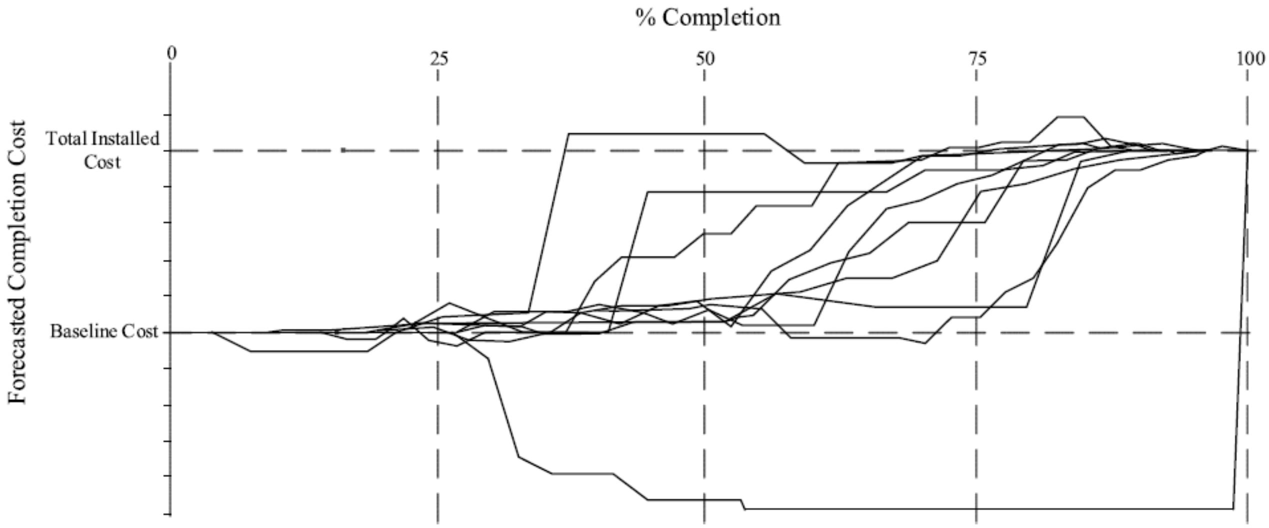
Figure 3. "Hockey stick" pattern – late disclosure of outcomes at completion

5.8 Schedule and Cost Deviations in Projects

Indeed, schedule and cost deviations, either overruns or underruns, are unfortunately, very common in the delivery of capital projects. Flyvbjerg et al. (2002) investigated 258 transportation infrastructure projects from 20 different countries and across a 70-year time period. The study reported an average cost overrun of 44.7% for rail, 33.8% for bridge and tunnel, and 20.4% for highway projects. In addition, trends of estimated accuracy improvements during the 70 years' timeframe were proved inexistent. In 2002, the UK treasury reviewed large public projects (inclusive of offices, hospitals, prisons, highways, roads, rails, airport terminals, and information and communication technology facilities) procured in a 20 years span (MacDonald, 2002). Average overruns of 17% on time, 47% on capital expenditures, and 41% on operating expenditures were reported. Recently, Mulva & Dai (2012) indicated that, based on the statistical analysis of 975 owner-completed projects, 70% of the projects experienced a ±10% or larger deviation from planned cost and time. These deviations are a major source of uncertainty and risk for the organizations in charge of delivering a project. The historic inability to reduce cost and schedule deviations denotes an endemic problem that the industry has yet been unable to tackle and resolve. For instance, in another recent study, Back and Grau (2013) reported a 10% median schedule deviation and a 14% median cost deviation at completion for 135 recently completed projects. For both cost and schedule, overruns and underruns were computed in absolute value.

5.9 AN INDUSTRY TREND OF LATE DISCLURE

Initially, we collected and investigated the cost and schedule forecast logs, and baseline and completion values for recently completed projects from a variety of organizations, project types, and industry sectors. Most often, the project manager reports the prediction of cost and schedule outcomes at a certain frequency, typically once a month. Thus, for a given project we define its cost forecast log as the sequence of cost prediction values and the timeline when each of such predictions was released, while the equivalent sequence of schedule prediction values and their corresponding timeline define its schedule forecast log. Data in each previously collected forecast log were normalized in its two dimensions to enable the comparison among projects. Such normalization of the forecast values within each log is detailed herein: (1) timeline at which the forecast was released relative to the total completion time, and (2) forecast error against the corresponding outcome at completion relative to the actual deviation at completion from the baseline. Indeed, the analysis of the normalized forecast logs provides evidence on the late, and hence inefficient, prediction of outcomes in industry projects. A trend to ascertain cost and schedule outcomes late in the project was identified, as Figure 4 illustrates with the sequence of forecasts generated through the timeline for multiple individual projects. For a distinct project, each line in Figure 4 captures the deviation at any moment in the completion timeline between the last (or prevalent) cost forecast and the actual installed cost. Figure 4 denotes a late disclosure of reliable outcome predictions, well into the second half of the project completion timeline, when corrective actions are unfeasible, difficult, and costly. Such pattern of late disclosure was observed for both cost and schedule prediction performance.



– Sequence of predicted forecasts during the completion of a project
(each line corresponds to a different project)

Figure 4. Cost forecast logs

The ability to predict is not likely to improve while project team performance solely relies on outcome-centric assessments. With such type of assessment, project teams will not feel compelled to become better predictors. For instance, it has been reported that, when progressively incentivized through the execution of a project, the project manager tends to adopt an optimistic and biased view toward the report of deviations with the hope that future corrective actions will effectively readdress performance (Back and Grau 2013a). With such types of incentives, deviations tend to be reported very late in the project execution process. In another example, it has been observed that predictability decreases without the oversight from the home office or from a third-party individual or organization. Without oversight, the likelihood for the true outcomes to be disclosed in a timely manner notably decreases (Back and Grau 2013a). To address this fundamental limitation, a refined mechanism to assess cost and schedule performance that incorporates the early disclosure of outcome completion values is herein proposed.

6 DATA COLLECTION

6.1 Qualitative and Quantitative Information

In order to determine the factors of influence on predictability, both qualitative and quantitative information on completed projects are collected. The data collection effort was very comprehensive and included 72 questions divided in on four main categories, as listed in the bullets below. Each question was framed around a factor of potential influence on predictability. Such factors had been previously determined through a literature review and through the provision of data and feedback from subject matter experts through workshops, research charrettes, and interviews.

1. Project characteristics (such as project type, location, complexity, use of new technologies, etc…);
2. Management processes (such as front-end planning, alignment, use of incentives, change management, etc…);
3. Forecasting practices (such as estimating methods, appropriate time to generate forecasts, data accuracy, reporting frequencies, etc…); and
4. Human and cultural aspects (such as trust, alignment, transparency, etc…)

Table i

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.

In addition to the 72 questions, the data collection effort also required the provision of cost and time forecast logs along the project completion. Such data was critical to generate the PI value for each project and hence assess its predictability performance.

In total, data for 135 completed projects was collected from major contractor and owner organizations. The data represents a total installed value close to $29 billion, and a total execution time close to 300 years. Private and public projects were almost equally represented, as were owner versus contractor type of projects. Projects were also representative of a large majority of industry sectors. Importantly, the authors also requested the provision of data from a spread of projects in terms of predictability. Hence, the database contained both early and accurate predictors and late and inaccurate predictors, and several other projects in between. Indeed, predictability values, understood as the sum of cost and schedule predictability, ranged from nearly 0 to values beyond several hundred in the dataset.

6.2 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.

6.3 Definition of Variables

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 5.

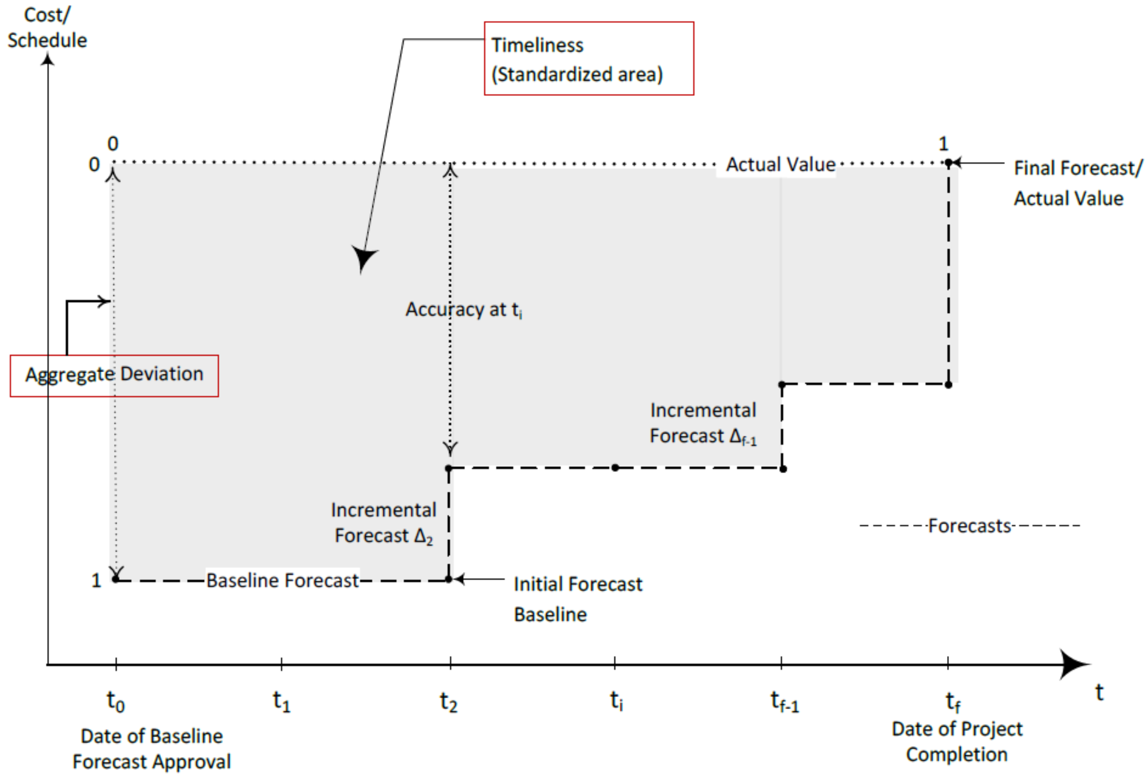


***Figure 5*. Predictability index components**

7 Predictability Index

This index 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.

7.1 The Predictability Index

The Predictability Index (P) represents the team's ability to accurately and timely predict cost and schedule performances. As such, it is defined as the sum of cost predictability and schedule predictability—see Eq. (1). Even though different arithmetic expressions through a combination of operators were evaluated, the aggregation of cost and schedule performances prevailed due to its consistency in the presence of extreme cost and/or schedule predictability performance values.

Predictability Index (P) = Cost predictability (CP) + Schedule predictability (SP) (1)

In the Predictability Index expression, cost and schedule performances are defined as the respective products between the normalized timeliness component times the percentage of deviation at completion—see Eq. (2) and (3). The lower the product between the deviation and normalized timeliness components is, the smaller the Predictability Index becomes—indicative of a better predictability performance. As defined in this study, the Predictability Index enables the assessment of the project team's cost and schedule performance at completion in three core competencies: (1) timeliness of forecasts, (2) accuracy of forecasts, and (3) deviations at completion

7.1.1 Cost Predictability (CP)

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.

CP = [Normalized Cost Timeliness] × [%Cost Deviation] (2)

7.1.2 Schedule Predictability (SP)

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.

$$\textbf{SP} = [\textbf{Normalized Schedule Timeliness}] \times [\textbf{\%Schedule Deviation}] \qquad (3)$$

The computation of the deviation and timeliness components for cost and time performances is described herein. On the one hand, cost and schedule deviations are expressed in Eq. (4) and (5) using their prevalent definition in the industry. The percentage of deviation is measured in absolute value, though, and hence ranges from 0% to, theoretically, any value, eventually beyond 100%

7.1.3 Cost Deviation

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.

$$\textbf{\%Cost Deviation} = \frac{|\textbf{Total installed costs} - \textbf{baseline cost}|}{\textbf{Baseline Cost}} \times \textbf{100} \qquad (4)$$

7.1.4 Schedule Deviation

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.

$$\textbf{\%Schedule deviation} = \frac{|\textbf{Actual completion time} - \textbf{baseline completion time}|}{\textbf{Baseline completion time}} \times \textbf{100} \qquad (5)$$

7.1.5 Timeliness

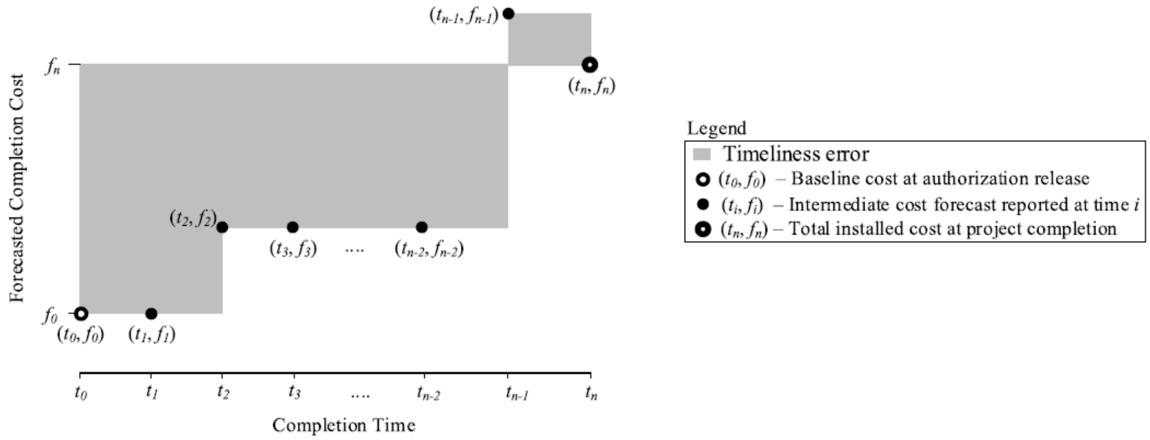


Figure 6. Late disclosure of outcomes

On the other hand, the timeliness component measures how fast and accurately the sequence of generated forecasts ascertained the actual completion outcome—regardless of the magnitude of the deviation. In short, getting to the correct outcome sooner, whatever that outcome might actually be, is much better than being surprised later when no mitigation actions are possible. In order to help the reader, grasp the concept of timeliness, Figs. 6 and 7 conceptually represent the cost timeliness error for two distinct forecast logs in which the total installed costs were both underestimated and overestimated during the completion timeline. Once a cost forecast f_i is generated at time t_i, the prediction or forecast error—the difference between f_i and total installed costs—is maintained until a new cost forecast f_i is generated at time t_{i+1}. Thus, Figure 7 shows early and accurate predictions f_i of total installed cost when compared to Figure 6—with late and inaccurate predictions. In each figure, the shaded area represents the timeliness error generated by project team predictions. Thus, at an equal percentage of deviation with the rest of project conditions remaining equal, it can be stated that the forecasting performance in Figure 7 is a better predictor of final costs than that in Figure. 6 since the timeliness error (the shaded area) in the former is smaller. In other words, the sequence of forecasts in Figure 7 informs better (more accurately and timely) on the final cost outcome than the sequence of forecasts in Figure 6. Inversely, at equal ability to approximate the time sequence of costs forecast to the total installed cost value, a smaller percentage of deviation is also indicative of an improved cost performance.

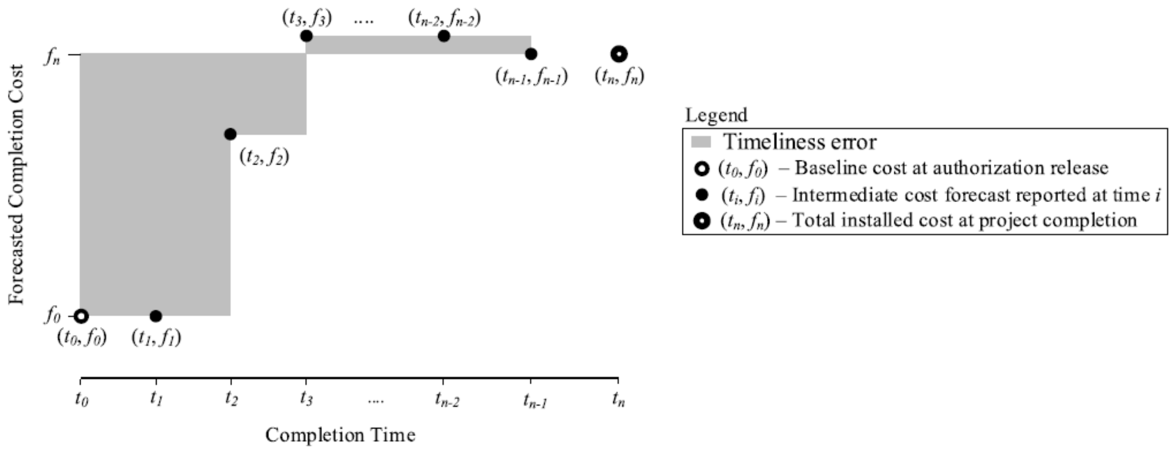


Figure 7. Improved disclosure of outcomes

A similar discussion can be used to explain the component of schedule timeliness. For normalization purposes, the timeliness error amounted between t_i and t_{i+1} is computed with the product between the forecasted error $|f_i$ –Total Installed Costs$|$ relative to the final deviation at completion and incurred time $(t_{i+1}–t_i)$ relative to the actual completion time. The normalized cost (NCT) and schedule (NST) timeliness expressions are defined in Eqs. (6) and (7), respectively. In the expression of NCT f_i denotes a cost forecast at completion generated at time t_i, while f_i denotes a schedule forecast at completion generated at time t_i in the expression of NST. A discussion on NCT values is herein provided. The cost timeliness value will always range from 0 (equivalent to a scenario in which all forecasts f_i generated at time t_i perfectly ascertained the total installed costs f_n) to a value eventually larger than 1. An NCT value of 1 is equivalent to maintaining all forecasts f_i equal to the baseline cost f_0 throughout the entire completion of the project. In other words, the closer the NCT value is to 0, the better the ability of the project team to timely predict total installed costs. The same insights can be used to assess schedule timeliness with NST values

7.1.5.1 Normalized Cost Timeliness (NCT)

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.

$$NCT = \sum_{i=0}^{i=n-1} \left|\frac{\text{fi} - \text{Total Installed Costs}}{\text{Baseline Costs} - \text{Total Installed Costs}}\right| \times \left(\frac{\text{ti+1 – ti}}{\text{Completion Time}}\right) \quad (6)$$

7.1.5.2 Normalized Schedule Timeliness (NST)

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.

$$NST = \sum_{i=0}^{i=n-1} \left|\frac{fi - Completion\ Time}{Baseline\ Time - Completion\ Time}\right| \times \left(\frac{ti+1 - ti}{Completion\ Time}\right) \quad (7)$$

8 Statistical Analysis to Test the Predictability Indices

8.1 Descriptive Analysis

In order to know the characteristics of the variables involved in the predictability indices, Table 8.1 shows the basic statistics of these variables, which will be used in the logistic regression models to test the indices.

Table 8.1 - 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

P=Predictability, CPI= Cost Predictability Index, CT= Cost Timeliness, CAD= Cost Aggregate Deviation,
SPI= Schedule Predictability Index, ST= Schedule Timeliness, SAD= Schedule Aggregate Deviation

8.2 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 statistically 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 (ΣR_+) and negative deviation ranks (ΣR_-) . 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 (Σ_+) and negative deviation ranks (Σ_-) . Table 8.2 shows a summary of the test.

Table 8.2 - 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 1. The second model involved the variable cost timeliness (NCT), as calculated with Equation 6. Finally, the third model involved the variable schedule timeliness (NST), as calculated with Equation 8.3.

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 R2 = 0.382; Nagelkerke R2 = 0.776). The model coefficients were statistically significant at $\alpha = 0.05$: B0 (Constant) = 2.420, Wald = 5.209, df = 1, p = 0.001; and B1 (P) = -1,408.079, Wald = 7.124, df = 1, p = 0.008. Equation 8 shows the final model of the binary logistic regression. 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 8.3 shows a summary of the test.

$$\Pi\ (\textbf{Cost \& schedule deviations} \leq 5\%) = \frac{1}{1+e^{-[2.420-1408.079P]}} \quad (8)$$

A second model included as predictor the variable Cost Timeliness (NCT), 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 R2 = 0.450; Nagelkerke R2 = 0.670). The model coefficients were statistically significant at $\alpha = 0.05$: B0 (Constant) = 2.382, Wald = 11.143, df = 1, p = 0.001 and B1 (CT) = -130.977, Wald = 15.177, df = 1, $p < 0.001$). Equation 9 shows the final model of the binary logistic regression. 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 8.3 shows a summary of the test.

$$\Pi\ (\textbf{Cost deviation} \leq 5\%) = \frac{1}{1+e^{-[2.382-130.977NCT]}} \quad (9)$$

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 R2 = 0.446; Nagelkerke R2 = 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 $\alpha = 0.05$: B0 (Constant) = 1.732, Wald = 10.204, df = 1, p = 0.001 and B1 (ST) = -59.489, Wald = 18.356, df = 1, $p < 0.001$). Equation 10 shows the final model of the binary logistic regression. 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.

$$\Pi \text{ (Schedule deviation} \leq 5\%) = \frac{1}{1+e^{-[1.732-59.482NST]}} \tag{10}$$

Table 8.3 - Logistic Regression Models Test Summary

Statistics		Model 1	Model 2	Model 3
Hosmer & Lemeshow Test	$\chi 2$ Df P	0.96 8 0.99	2.116 8 0.98	46.984 8 < 0.01
Nagelkerke	R2	0.78	.67	0.64
B_0	b_0 Wald Df P	2.42 5.209 1 < .01	2.38 11.143 1 < .01	0.732 10.204 1 < .01
B_1	b_1 Wald Df P	-1,404.08 7.124 1 < .01	-130.98 15.177 1 < .01	-59.49 18.356 1 < .01

8.3 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 8, 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 8). 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.

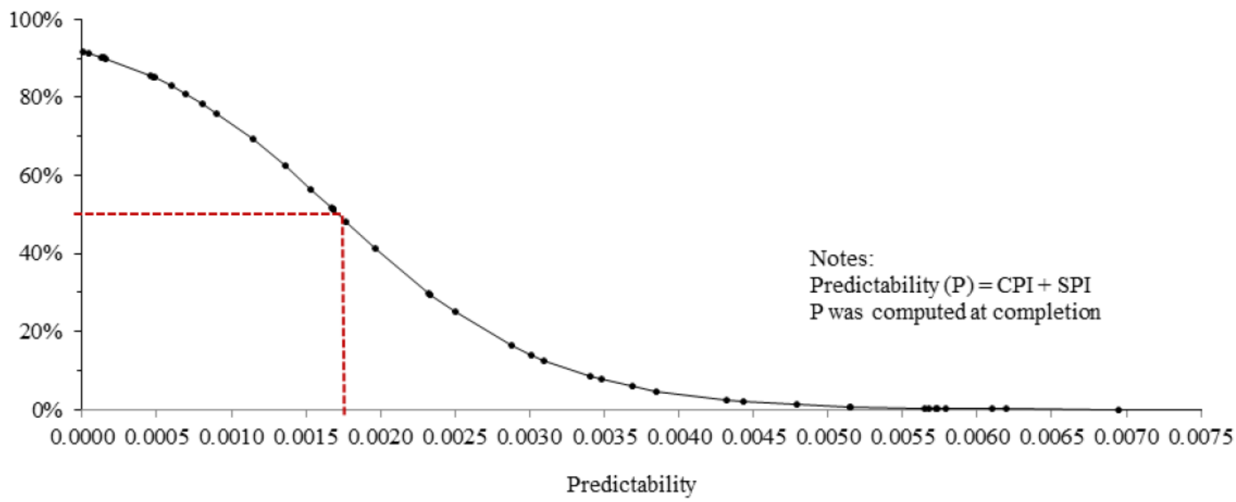


***Figure 8*. Probabilities of Deviations Less than 5% by Predictability**

Likewise, based on the second logistic regression model of Equation 9, 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 NCT was less than 0.018 (see Figure 9). The respective odds ratio indicated that as NCT 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 NCT 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.

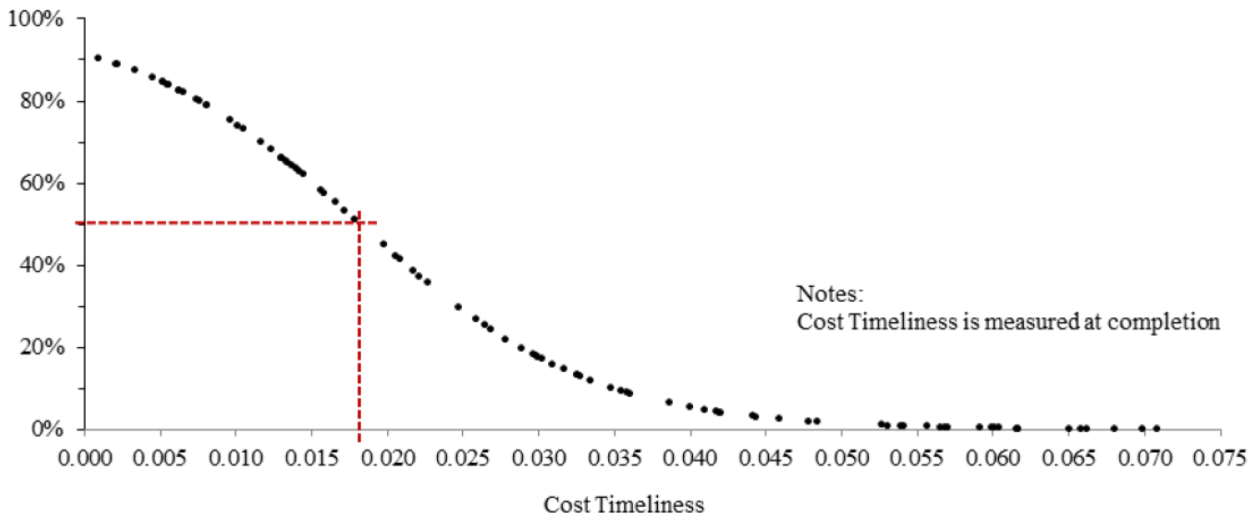


***Figure 9*. Probabilities of admissible cost deviation by timeliness.**

Finally, based on the second logistic regression model of Equation 10, 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 NST was less than 0.029 (see Figure 9). The respective odds ratio indicated that as NST 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 NST 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.

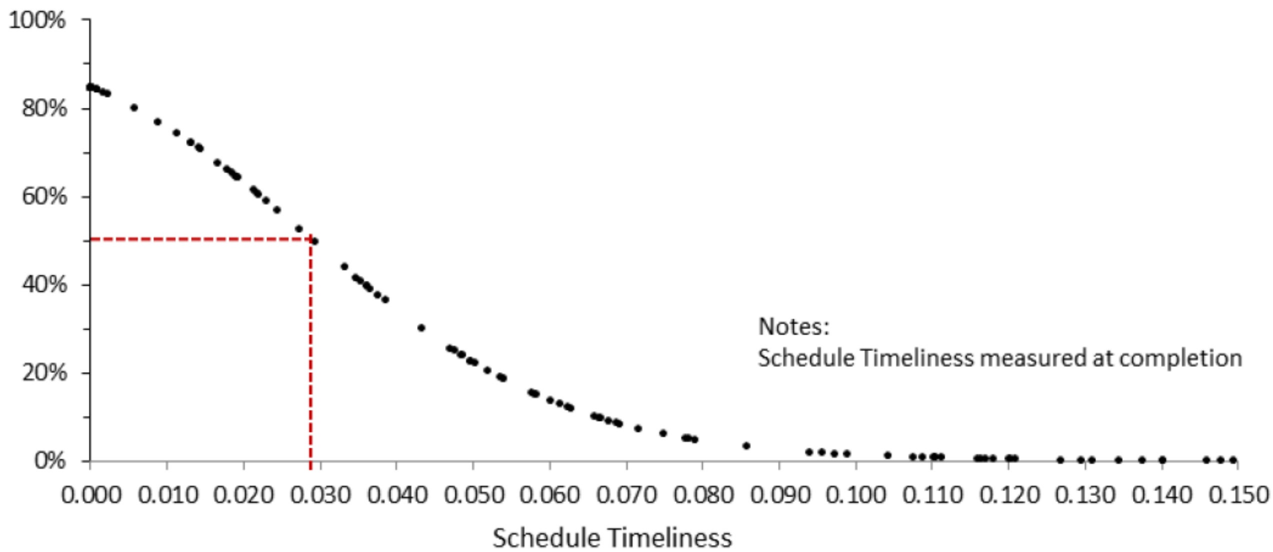


***Figure 9*. Probabilities of admissible schedule deviation by timeliness.**

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.

9 Discussion and Contribution

This study proposed to evaluate the predictability index and its component timeliness. The results demonstrated that timeliness (i.e., NCT, NST) 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.

9.1 Assessing Predictability Performance

In order to support the evaluation of project team performance, this section provides guidance on how to assess the Predictability Index and its components. To this end, a survey instrument was used to collect retrospective project data. Specifically, an electronic survey tool was designed to request detailed data on project characteristics, forecasting practices, management process, and the project forecast logs for both cost and schedule. Once the survey instrument had been pilot-tested by a group of 13 subject matter experts, the survey was distributed among owner and contractor organizations. In all, we collected 135 survey responses on completed projects. Of the 135 projects, over 90% had been completed within the last 5 years. The total dollar value of the projects was $28.88 billion, with an accumulated completion time close to 300 years. The median schedule deviation was 7.91% and the median cost deviation was 5.93%. The data set encompassed responses from a variety of organizations, functions, project types, and sectors, as Tables 1–4 illustrate.

Table 1. Role

Role	%
Owner	48
Contractor	52

Table 2. Project Type

Project type	%
Public	45
Private	52
Both	3

Table 3. Function

Function	%
Owner/client	47
Design build	19
Architectural/engineering	29
Procurement	31
Contractor	30
Construction management	28

Table 4. Industry Sector

Sector	%
General building	7
Pulp and paper	1
Light industrial	2
Manufacturing	7
Power	14
Petroleum upstream	6
Petroleum downstream	18
Heavy industrial	7
Chemical	30
Highway and infrastructure	2
Technology and electronics	2
Others	18

Through the statistical analysis of the collected data, we sought to provide an assessment on predictability values that can be used to differentiate the goodness of cost and schedule performance. To this end, we computed the Predictability Index for each of the 135 projects. Then, thresholds of performances were identified by sorting out the 135 projects in quartiles: the first quartile associated with very good predictors; the second quartile associated with good predictors; the third quartile associated with poor predictors; and the fourth quartile associated with the very poor predictors.

Table 5 outlines the threshold values that differentiate these four levels of predictability performance and hence that, from a statistical perspective, differentiate the ability of project teams to predict cost and schedule outcomes altogether. As shown in Table 5, the minimum possible index corresponds to 0 and is indicative of a project that has been completed with null deviations or with an immediate and accurate ability of the project team to predict such deviations.

Table 5. Predictability Index Threshold Values

Predictability performance	Predictability index	
	Minimum	Maximum
Good	0	7.9
Medium	>7.9	17.6
Poor	>17.6	31.7
Very poor	>31.7	None

9.2 Cost and Schedule Predictability

In reality, project sponsors frequently prioritize either cost or schedule, and thus the need to provide guidance on how to assess the predictability performance for either metric is addressed herein. For example, assume, on the one hand, that the project team forecasted the completion of a schedule-driven project without error— i.e., SP = 0. On the other hand, also assume that the project team was unable to foresee a significant cost deviation until late in the project—i.e., equivalent to a large CP value. For such a team, its predictability performance index would be rather large despite its strong prediction performance in schedule, and hence would fail to provide a fair assessment of individual cost and schedule performances. Thus, the tables below contain the cost predictability (Table 6) and schedule predictability (Table 7) threshold performance values. Please notice that such threshold values were independently generated by sorting out the 135 projects by cost predictability performance and, separately, by schedule predictability performance. Thus, the values in Tables 6 and 7 prioritize cost and schedule performances alone, and, when added, the resulting value is not necessarily consistent with the threshold values of aggregate predictability in Table 1. For a combined cost and schedule predictability assessment, the threshold values in Table 1 should always be considered.

Table 6. Cost Predictability Threshold Values

Cost performance	Cost predictability Minimum	Cost predictability Maximum
Very good	0	3.5
Good	>3.5	7.8
Poor	>7.8	15.2
Very poor	>15.2	None

Table 7. Schedule Predictability Threshold Values

Schedule performance	Schedule predictability Minimum	Schedule predictability Maximum
Very good	0	4.2
Good	>4.2	8.6
Poor	>8.6	22.5
Very poor	>22.5	None

9.3 Timeliness

Finally, in order to assess the timeliness to ascertain actual cost and schedule outcomes, the timeliness component of predictability was also evaluated. The reader should recall that the timeliness expresses how timely and accurately the team ascertained the actual cost or schedule outcomes, irrespective of the magnitude of the deviation at completion. Thus, as previously pointed out, at an equal percentage of deviation with the rest of project conditions remaining equal, a smaller normal timeliness component indicates an improved ability to ascertain actual project outcomes—see Figure 3. Table 8 contains the threshold values that differentiate the four quartiles of cost timeliness performance, while Table 9 contains the equivalent threshold values in schedule timeliness performance. Notice that a unitary (=1) timeliness performance is equivalent—but not necessarily equal—to the generation of each forecast throughout the project timeline with the same baseline value in spite of the existence of deviations at completion. Thus, that the team's ability to forecast reduces the normalized timeliness below 0.6 is indicative of a strong ability to accurately predict final cost or schedule outcomes early in time, as Table 8 illustrates.

Table 8. Normal Cost Timeliness Threshold Values

	Timeliness error	
Timeliness performance	Minimum	Maximum
Very good	0	0.4
Good	>0.4	0.6
Poor	>0.6	0.8
Very poor	>0.8	None

Table 9. Normal Schedule Timeliness Threshold Values

	Timeliness error	
Timeliness performance	Minimum	Maximum
Very good	0	0.3
Good	>0.3	0.6
Poor	>0.6	0.8
Very poor	>0.8	None

10 Lessons Learned and Observations

The lessons and observations presented in this section are based on factual insights from the adoption of the proposed predictability assessment by industry organizations. These insights exemplify the substantial cultural shift necessary to become "predictability-focused" as an organization. Such focus on predictability also requires organizations to rethink their overall project management and controls approach and the way project team participants generate and communicate information. The rest of this section highlights key issues observed in the adoption of cost and schedule predictability performance.

10.1 Leadership and Cultural Shift

Organizations willing to assess cost and schedule predictability performance must reinforce and promote values such as personal and corporate trust, ethics, timely and uncompromised disclosure of information, or alignment. A top-down communication approach stemming from upper management's full support and meaningful endorsement is necessary to successfully move toward cost and schedule assessments based on predictability. Without upper management's explicit support, such adoption is not possible. It has also been observed that adoption efforts need to be accompanied with training and also with exposure to predictability practices and tools—for the latter, please refer to Back and Grau (2013a) and Back and Grau (2014). Upper management needs to clearly communicate and reiterate a message of establishing behaviors and practices that emphasize the need for reliable and trustworthy predictions of project outcomes.

10.2 Predictability as a Benchmarking Metric

We have documented internal benchmarking efforts based on predictability performance. In these efforts, organizations longitudinally track predictability against variables such as business unit, project size, geographical sector, team leadership, or capacity, among others. For instance, projects in new or unfamiliar geographical locations are observed to often result in low predictability performance when compared to similar projects in familiar or known locations. Additionally, the benchmarking of predictability performance is also perceived as a reinforcing message within itself, promoting behavioral shifts in the organization that emphasize trust, transparency, alignment, and timely disclosure of project performance information.

10.3 Learning by Measuring—From Discretionary Contingency Allocation to Cost Escalation

In the context of an owner organization, upper management decided to analyze the predictability performance on recently completed projects. The analysis of the cost predictability performance indicated the existence of a set of projects with what upper management ultimately referred to as "dual cost performance." These projects consistently generated forecasts identical or nearly identical to the authorized budget until half of the completion timeline. However, any such project was observed to either keep the baseline cost through completion (i.e., with nearly null deviations) or actually suffer from large cost deviations at completion. Through a detailed analysis of the second subset of projects, it was diagnosed that the actual cause of such late disclosure of cost deviations was a misuse of contingency reserves. Indeed, such projects suffered from a variety of underlying issues (e.g., low productivity ratios, price escalation, labor shortages, etc.) that, even though not included in the risk register, were compensated through a discretionary allocation of contingency reserves. Once all the reserves had been used, the cost impact of such issues could not be compensated any longer and project costs invariably soared until completion. In response to such findings, upper management decided to adopt the following mechanisms of control: **(1) enforced use of contingency reserves against items in the risk register, and (2) scrutiny of projects reporting null or nearly null cost deviations at 25% completion.**

10.4 On Cost Performance—Predictability Versus Deviations

In a multibillion-dollar project scenario, the project team was instructed and trained in predictability performance before undertaking the project effort. Due to the high dollar value of the project and the ripple implications from potential cost deviations, upper management required the exposure of the team to predictability with the expectation that true outcome predictions would be reported early as opposed to late in the execution phase. Training efforts were aimed at exposing the team to the importance of an early disclosure of final outcomes, as well as providing the team with tools and practices to improve the team's ability to predict. Also, a culture of trust was established so that team members would not develop a sense of fear for scrutiny or reprisals if deviations were to be reported. As important as final deviations were, upper management clearly set the reporting of accurate and timely predictions as a priority. In fact, at 30% completion the team reported a cost deviation above 20%. Corrective actions were immediately implemented with the aim to prevent further escalation of project costs and also to balance the capital investment program in the organization. Embracing the cultural shift towards predictability, upper management reminded the team of the need to contain deviations, but, at the same time, congratulated team members for the early disclosure of such critical cost information.

11 Conclusions

Making any prediction of future performance, particularly with respect to final cost and schedule, is a difficult endeavor. Owners and contractors alike base key strategic decisions on their project forecasts, and typically ask project teams to make continual refinements to cost and schedule predictions, with the goal of providing management with valid, timely, and reliable information. However, the ability to accurately predict project outcomes is highly varied within the industry, sometimes even within a single organization. This variability means that all too often, many companies experience “surprises” or unexpected negative consequences.

This study contributes to the body of knowledge in 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. The predictability indices are quantitative measures to determine the timeliness and accuracy of cost and schedule predictions during the execution of a project. In this study we have presented a novel approach to assess cost and schedule performance based on the ability of project teams to accurately forecast actual installed costs and completion time as early as possible in the project timeline. Such evaluation of cost and schedule performance represents a significant departure from current assessments of team performance solely based on actual deviations at completion. A cultural shift is required for organizations to instill the attitudes and behaviors necessary to understand that, given the existence of a deviation, profitability losses are minimized through an early disclosure of such deviation, and hence that such early disclosure is necessary. Indeed, project teams cannot eliminate the events that can and will affect a project, but they can, and should, mitigate the effect of such events with their early recognition, and transparent and candid reporting. The rationale is that being proactive, rather than reactive, in the recognition of trends and events significantly improves the team’s ability to minimize the gap between predicted and actual outcomes. Overall, the value of becoming predictable lies in that predictions set expectations of project outcomes, provide the basis for important adjustments for both individual projects and the capital investment program, and hence drive decision-making processes. Future studies should investigate the factors that influence predictability, so that owner and contractor companies can improve their predictability performance. The understanding of such influencing factors should enable organizations to foresee impending cost and schedule deviations, implement appropriate practices and processes, and encourage an organizational behavior that promotes trust, transparency, and accountability.

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