The Predictability Index – A Novel Project Performance Metric to Assess the Early Prediction of Cost and Time Outcomes

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ABSTRACT
As a departure from the current state of practice, 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. To enable the assessment of predictability performance, a novel Predictability Index metric is proposed, investigated, and discussed. Based on the statistical analysis of data for 135 completed projects representing $29 billion in total installed costs, the Predictability Index measure is characterized and the major influencing factors on project predictability performance are unveiled. 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.

MOTIVATION
The construction industry has historically had a prominent role in the economic and social development of the US, for which construction is a major indicator for economic health. In 2012, despite the recent economic downturn, the construction sector employed more than five million workers (BLS, 2013), construction spending amounted to excess of eight hundred billion dollars (US Census, 2013) or an equivalent of 5.5% of the Gross Domestic Product (GDP). However, despite this importance, the delivery of a capital project, fundamental to the wellbeing of the industry, frequently turns into an unpredictable endeavor that results in cost and schedule deviations at completion (Flybjerg et al., 2002; Back & Grau, 2013; Mulva & Dai, 2012). Such deviations, either above (overruns) or below (underruns) the initial baselines or target values, result in a lost opportunity to
increase the value of a project (Mulva & Dai, 2012), and, overall, negatively affect industry organizations and hinder its positive impact to the society.

Many and varied factors can influence and impact the performance of a given project (Flanagan & Norman, 1993; Smith, 2003; Akintoye & MacLeod, 1997; Back & Grau 2013). Despite the importance of early cost and schedule estimates for the sponsoring organization and project team, these estimates are frequently in significant contrast to the achieved outcomes (Oberlender & Trost, 2001). Deviations can stem from multitude of sources such as geographic location, complexity, implementation of new technologies, scope changes, escalation, workforce issues, or type of project (i.e. greenfield, brownfield, renovation), just to mention a few (Flanagan & Norman, 1993; Back & Grau, 2013). Also, poor front end planning or the lack of a complete scope definition in the early stages of capital projects will render estimates inaccurate. Such influencing factors directly alter the project delivery process and hence affect project performance success in terms of cost, time, quality, and safety (Flanagan & Norman, 1993). While safety has one (and only one) target performance goal (zero accidents), the evaluation of quality performance is subject to different and subjective interpretations that can greatly vary across projects and involved organizations. Thus, even though this study acknowledges the existence of cost, schedule, quality, safety, and also other measures of performance, the scope of this research is limited to cost and schedule metrics.

In order for an organization to properly allocate budget, time, and resources within a project and across its portfolio of projects an accurate prediction of project outcomes becomes a prerequisite (Back & Grau, 2013). Without such accurate prediction of project outcomes, managers cannot effectively level resources in order to maximize corporate outcomes, such as profit, competitiveness, or market share, among others. As an example, if a cost overestimate was identified early in the project, excess funds could be allocated to new or existing projects to maximize profitability. In an opposite situation in which a cost underestimate was also identified early in the project, timely provisions could be accounted for in the financial portfolio of the company in order to mitigate such deviation. In any case, though, getting to know the accurate cost and schedule outcomes of a project early in the delivery timeline is critical to maximize the value of an individual project and its value to the organization across its capital investment and operation efforts.

Thus, as a departure from the current state of practice, this study proposes to evaluate cost and schedule performance based on the early and accurate prediction of their final outcomes, as opposed to the prevalent standalone evaluation of final cost and schedule deviations at completion. Unarguably, project performance to date on a given project reflects the history of time and cost investments, which have a clear value in any decision making process. However, the ability to recognize and accurately project deviations early in the project delivery timeline becomes a critical practice to ensure that the correct decisions can be properly made early in time. Whatever the answer or outcome of a project may be, getting to know such answer early in the project has a significant value both to the project, contractor, and sponsor organizations.

The remainder of this paper is organized as follows. The next section reviews estimating techniques and emphasizes the need for accurate predictions based on
endemic project deviations. The proposed definition of the Predictability Index as a performance metric precedes the data collection methodology and statistical analyses. Finally, this manuscript discusses results and observations collected from the actual implementation of the Predictability Index.

BACKGROUND

Project control encompasses monitoring incurred cost and time resources to project date and also to reliably predict cost and schedule outcomes at completion. During the delivery of a project, several levels of cost and schedule estimates can be generated based on their level of definition. Indeed, the Association for the Advancement of Cost Engineering (AACE) (AACE, 2011) defines a cost classification system based on the “maturity level of project definition deliverables”. The project definition maturity level is expressed as a percentage of the scope of work completeness used to generate the cost estimate. The project definition maturity level is divided into 5 classes, with class 5 being the least defined phase of the project used at the screening/feasibility phase, and class 1 being the most complete scope definition used at the bid/tender phase. Other intermediate estimate classes are categorized as follows: class 4 is used during project concept study; class 3 is used at the budget authorization or control phase; and class 2 is used at the control or bid/tender phase. It is noted that with higher project maturity levels the expected estimate accuracy improves but the required preparation time and effort also increase, since more detailed information needs to be collected and processed. A similar classification system can easily be adopted to classify schedule estimates, from master plan to weekly work plans. During the delivery of a project, the cost and time estimates associated with the release of funds and order to proceed commonly become the reference or baseline values to which cost and schedule deviations will be measured during both execution and at project 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. Wheelwright (1995) concluded that there is no universal superior deterministic forecasting approach, even though most organizations are rooted in the Earn Value System (EVS). Deterministic approaches are typically less accurate than probabilistic approaches since a single estimate is projected, as opposed to a range of possible estimates, each of them associated with a degree of certainty. To overcome this inherent limitation associated with deterministic approaches, probabilistic and range estimating methods have been developed. Such probabilistic methods generate upper and lower bound estimates, and hence can better predict the variable behavior of capital projects (Diekmann, 1983; Curran, 1989; Isidore & Back, 2002). These probabilistic methods enable a stochastic assessment of project cost and schedule estimates, thus allowing the planner to make estimates with a sufficient degree of certainty in order to minimize variability (Isidore & Back, 2002). 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).
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 1).

![Figure 1. “Hockey stick” pattern – late disclosure of outcomes at completion](image)

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.
A NOVEL PERFORMANCE EVALUATION PERSPECTIVE – THE PREDICTABILITY INDEX

It is a traditional mindset within the industry to evaluate project performance based on deviations at completion alone. Such mindset, though, is aligned, or at least permissive with the late disclosure of cost and time values at completion, as presented in Figure 1. If any deviation from cost and time performance hinders the net present value of a project (Mulva & Dai, 2012), the late disclosure of actual cost and time completion values further hinders such value. Events will invariably affect project performance, but the rapid identification and provision of data on such events can be incorporated to generate reliable forecasts.

As a departure from the current state of knowledge, this study proposes a novel metric, the Predictability Index, to measure cost and time performance. Such approach is not based on final deviations alone, but also on how early such deviations were ascertained or projected by the project team. The control of a project should focus not only on assessing the consumed cost and time resources, the history of the project, but also on reliably projecting what the cost and schedule outcomes will be. In other words, a time dimension perspective is added to the traditional performance evaluation of cost and time metrics based on final deviations at completion alone.

As shown below, the Predictability Index is defined as the sum of cost and schedule predictability measures. Projects with a better predictability performance show a lower Predictability Index when compared to projects with large deviations.

\[
\text{Predictability Index (PI)} = \text{Cost Predictability (CP)} + \text{Schedule Predictability (SP)}
\]

The cost and schedule predictabilities separately indicate how accurately the forecasted values along the project completion ascertained the final cost or time outcomes. Each of these predictabilities results from the product of normalized timeliness times the absolute deviation error, in percentage of deviation from the baseline.

\[
\text{CP} = [\text{Normal Cost Timeliness Error}] \times [\text{ABS (% Cost Deviation Error)}]
\]

\[
\text{SP} = [\text{Normal Schedule Timeliness Error}] \times [\text{ABS (% Schedule Deviation Error)}]
\]

The normal timeliness error accounts for the accuracy of predictions along the project completion timeline, and is separately computed for cost and time metrics. The area between the predicted and actual values compounded along the project timeline is equivalent to the normal timeliness error. Figure 2 shows two conceptual examples of the normalized cost timeliness components for two projects with underestimated costs -thus, the timeliness error areas are shown entirely below the actual cost values.

Project A (see Figure (a)) represents an early and accurate cost predictor, while Project B (see Figure (b)) represents a late predictor of actual completion costs. According to the above Cost Predictability equation, for the same percentage of cost deviation, Project A is a much accurate predictor than Project B because of its smaller
normal cost timeliness error. A similar reasoning can be used to discuss schedule predictability performance.

![Diagram of Normal Cost Timeliness Errors](image)

(a) Project A

(b) Project B

**Figure 2. Normal Cost Timeliness Errors**

**DATA COLLECTION**

In order to determine the factors of influence on predictability, the authors collected both qualitative and quantitative information on completed projects. The data collection effort was very comprehensive and included 72 questions divided into 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…)

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 (see Figure 4). 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.

PREDICTABILITY ASSESSMENT AND FACTORS OF INFLUENCE

The PI values for the 135 projects were ordered, and interquartile ranges were defined. Such values were used to characterize the predictability performance of a project based on the accurate and early prediction of project outcomes. Table 1 presents the interquartile ranges of predictability, which provide a measure of predictability performance –very good, medium, poor, and very poor. The reader should recall that, the better the predictability, the lower the PI value. Additional predictability performance measures for time and cost were also computed.

<table>
<thead>
<tr>
<th>PI measure</th>
<th>Predictability Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI ≤ 8</td>
<td>Very Good</td>
</tr>
<tr>
<td>8 &lt; PI ≤ 18</td>
<td>Medium</td>
</tr>
<tr>
<td>18 &lt; PI ≤ 32</td>
<td>Poor</td>
</tr>
<tr>
<td>PI &gt; 32</td>
<td>Very Poor</td>
</tr>
</tbody>
</table>

Also, the correlation between the influencing factors and predictability was determined through a bivariate and categorical correlation analysis. Correlation was measured using the Spearman’s correlation coefficient rho (ρ) as a nonparametric measure of association. Among the statistically significant practices with an influence on predictability, the practices in the human behavior and organizational culture
category were prevalent. This prevalence is indicative of its major influence on predictability. Indeed, the human behaviors and organizational culture category accounted for approximately 64% of the practices correlated with predictability, while the other three categories—project characteristics, management processes, and forecasting practices—each only accounted between 28%, 44%, and 48%, respectively.

**DISCUSSION**

During this study, the authors have met with numerous industry leaders and subject matter experts on both project management and project controls from leading contractor and owner organizations. When exposed to the concept of assessing project team performance through the novel Predictability Index, the feedback from industry leaders and subject matter experts was definitively very positive and strong. For instance, several large owner and contractor organizations have not only implemented the Predictability Index to assess project performance, but they also worked to change the mindset of their project teams in order to provide an early disclosure of cost and time completion outcomes. For example, in the context of a large and complex project, a substantial (above 30%) cost deviation was reported by the project team very early in the execution phase. Even though the chances to fully remediate such large cost deviation before project completion were evaluated as low, the company officers positively valued the project team and internally showcase them as an example. Company officers valued two aspects of such early disclosure of completion costs. First, it enabled the project team to implement remediation actions in order to reduce the cost overrun, or at the least to prevent its escalation during the execution of the project. Second, it provided important financial information that could be utilized in order to leverage the cash flow of the project and the use of financial resources across the company’s portfolio of projects.

In another implementation effort, the analysis of the forecasted values along the timeline of several completed projects by the same organization denoted an endemic problem of late disclosure of accurate cost and time completion outcomes. A detailed analysis of such late-reporting behavior disclosed the misuse of contingency reserves to cover trends and events that had not been accounted for in the risk register. Once the contingency was exhausted, typically beyond the midterm execution dateline, cost and schedule deviations were invariably reported, since the events and trends that generated them had not been properly identified or mitigated while compensated through contingency reserves. Such late reporting of deviations precluded proactive actions to address project execution and negatively impacted the management of the capital resources within the organization.

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