



EMPIRICAL STUDY OF RELATIONSHIP BETWEEN COST PERFORMANCE INDEX STABILITY AND PROJECT COST FORECAST ACCURACY IN INDUSTRIAL CONSTRUCTION PROJECTS

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Abstract: Reliable estimation of project completion costs throughout the life cycle of a project can be used to guide decision-making and proactively enhance project execution. Cost performance index (CPI)—a measure obtained using the integrated earned value management (EVM) approach—has been used to forecast estimated at completion (EAC) costs in practice. CPI, however, can fluctuate throughout a project, and forecasting EAC costs using a variable index may lead to unreliable results. Yet, despite its potential impact on forecasting accuracy, CPI instability and its effect on EAC forecasting of construction projects, particularly in the industrial construction sector, remains relatively unexplored. An empirical study of 35 projects was conducted to determine the stability point and examine the effect of CPI instability on industrial construction projects. In contrast to previous reports, over half of the projects stabilized after the 80% project completion point. Although CPI stability point was found to inversely correlate with EAC forecast accuracy, the association of these variables depended on the forecasting method. Indeed, the EAC forecasting accuracy of a technique that considered other project conditions (e.g., unapproved changes, ordered material, etc.) in addition to CPI, was not correlated with CPI stability. These results indicate that industrial construction projects are characterized by relatively late project stability and suggest that late stability may affect forecasting accuracy of industrial construction projects, particularly when using CPI-based forecasting methods.

1 INTRODUCTION

Reliable estimated at completion (EAC) cost forecasts are essential for optimal project management, acting as an early warning of poor project performance (Fleming and Koppelman 2016), guiding decisions regarding the initiation of corrective actions (Batselier and Vanhoucke 2015), and, in certain cases (e.g., military construction), signaling early project termination (Christensen and Heise 1992). Construction projects, however, are complex systems comprised of a large variety and number of work packages and are, consequently, notoriously difficult to manage and forecast (Ahuja et al. 1994). Earned value management (EVM) was introduced by the U.S. Federal Government in the 1960s as a project control tool that integrates project scope, cost, and schedule to provide early project performance indicators and warnings to practitioners (Fleming and Koppelman 2016). EVM uses two indices to assess cost and schedule performance, namely cost performance index (CPI) and schedule performance index (SPI), respectively.

In addition to indicating the cost effectiveness of performed work, CPI can also be used to forecast the estimated at completion (EAC) cost of a project. However, construction project performance and, in turn, CPI can vary considerably as a project evolves (Lipke et al. 2009): a project may be characterized by good cost performance in the early stages of project execution yet exhibit poor performance upon completion. Indeed, the learning curve effect (Batselier and Vanhoucke 2017), project conditions (Cheng et al. 2010) and differences in performance of various activities (de Souza et al. 2015) have all been associated with CPI instability. In these instances, the use of CPI to forecast EAC costs may provide misleading information about a project. While previous studies have examined CPI stability in construction, the appropriateness of CPI-based EAC cost forecasting for industrial construction projects has yet to be examined.

This study conducted an empirical analysis of historical data from 35 industrial construction projects; CPI stability throughout the life cycle of a project and the impact of CPI variability on these projects was determined. In contrast to other studies, a majority of the studied projects did not stabilize until the 80% completion point. CPI stability and EAC forecast accuracy were analyzed. CPI stability was inversely correlated with EAC cost forecasting accuracy. In general, early project CPI stability was associated with the generation of more reliable project estimates. Results of this study can be used to (1) better inform practitioners of the reliability of their forecasted results and CPI stability in practice, (2) assist in assessing the appropriateness of their chosen forecasting method, and (3) estimate the accuracy of EAC cost forecasts based on the CPI stability level of a project.

2 LITERATURE REVIEW

Reporting EAC has become a routine part of monthly reports. In addition to conventional methods for project cost forecasting [e.g., unit area cost (UAC) and unit price analysis (UPA) (Bayram and Al-Jibouri 2016)], various EAC forecasting techniques have been proposed. Cheng et al. (2010) used an evolutionary vector machine inference model to predict final project costs of high-rise buildings; historical performance data, along with data related to climate, project performance, and market pricing data, were used to build their prediction model. Batselier and Vanhoucke (2017) used an exponential smoothing-based method to improve project cost and duration forecasts. Their method incorporated trends and changes resulting from the learning curve effect or managerial decisions into EVM calculations. To investigate project cost performance stability at a lower level (e.g., a work package level), Kim (2015) utilized Monte Carlo simulation to assess project stability time. It has been suggested that CPI stability at the project level depends on the work package level, and variation in the work package level will affect CPI stability (Kim 2015). Project cost performance is a stochastic process that varies over time. Du et al. (2016) combined Markov Chain and Monte Carlo simulation to forecast CPI using historical cost performance data. Bayram and Al-Jibouri (2016) compared forecast accuracy of regression analysis with four, different, non-traditional methods (e.g., multilayer perception, radial basis function, grid partitioning algorithm, and reference class forecasting) in an empirical study. These authors concluded that different methods can outperform others for certain applications, and there is no single best method for forecasting cost.

Many of the methods designed to enhance EAC accuracy proposed in literature, such as those previously mentioned, are quite complex and require the input of data that are not readily available in practice. Accordingly, practitioners are often inclined to use methods that are more straightforward. Due to their ability to incorporate ongoing project performance and their ease-of-use, EVM-based methods for EAC cost forecasting are among the most commonly used methods in industry. Several EVM-based cost forecasting calculations exist (summarized in Table 1). Each formula has its own assumption and is applied to calculate EAC cost forecast based on project manager discretion and project conditions.

Table 1: EVM-based EAC cost forecasting formulae (Fleming and Koppelman 2016)

	Formulae*
Optimistic Estimate [^]	$CV = EV - AC$ $EAC = BAC + CV$
Pessimistic Estimate [^]	$EAC = \frac{BAC}{CPI}$
Formulae Considering Schedule Delays	$EAC = AC + \frac{BAC - EV}{(CPI * SPI)}$ $EAC = AC + \frac{BAC - EV}{(\alpha * CPI + \beta * SPI)}$ $\alpha + \beta = 1$
<p>*Where CV = cost variance; EV = earned value; AC = actual cost; BAC = budget at completion</p> <p>[^]Based on the assumption that project is running over budget</p>	

CPI of a project, defined in Equation 1, is a factor in a majority of these formulae. In these instances, fluctuations in CPI value will result in EAC cost forecast variability. Although several definitions of CPI stability have been proposed (Petter 2014), the formula first developed by Christensen and Payne (1992), which defines the CPI stability point as the percent completion of a project at which the CPI value (CPI_x) varies less than 0.1% of its final value (CPI₁₀₀), is used in the present study (Eq. 2).

[1] $CPI = EV/AC$

[2] $|CPI_{100} - CPI_x| \leq 0.1$

In 1994, Christensen conducted an empirical study of defense projects and found that these projects stabilized around the 20% completion point (Christensen 1994). In contrast, Henderson and Zwikael (2008), analyzing historical construction project data from the UK, determined that only two out of ten projects studied achieved stability at the 20% completion point, demonstrating that CPI stability points should not be extrapolated across various project types. Additional, construction-type focused studies are required to gain a more precise understanding of CPI behavior over the life cycle of a project as well as the effect of CPI instability on EAC cost forecasting accuracy.

3 RESEARCH METHODS

A total of 35 industrial constructions projects executed in northern Alberta by a major contractor located in Alberta, Canada, were selected for the empirical analysis. Project durations ranged from 4.0 to 14 months, with an average duration of 7.1 months. Dollar values (in CAD) of projects ranged from 0.3 to 24 million, with an average value of 6.7 million dollars.

3.1 CPI Stability Assessment

A threshold of 0.1 was selected to determine CPI project stability (Christensen and Payne 1992). CPI stability points were determined using Equation 2. Here, the overall CPI stability point of a project was defined as the earliest point of project completion where CPI was stable that was not succeeded by two or

more months of instability. For example, if a project with a duration of 10 months has stable CPIs at months 3-5 and 6-10, the CPI stability point is 30%. In contrast, if the same project has stable CPIs at months 3-5 and 7-10, the CPI stability point is 70%.

3.2 EAC Forecast Error Calculation

EAC values were calculated using the CPI-dependent method described in Equation 3, and average EAC forecast error for a project was calculated using Equation 4.

$$[3] \text{ EAC} = \frac{\text{BAC}}{\text{CPI}}$$

$$[4] \text{ Average EAC forecast error} = \frac{\sum \frac{|Final\ cost - EAC_t|}{Final\ cost}}{\frac{T}{A}}$$

Where EAC_t is the value of the forecast at month t , and T is the total project duration in months. EAC forecast values of the case company, generated using a combination of expert judgement and various project indicators, were obtained from monthly company reports. Since EAC in the studied company was not calculated based on CPI values alone, examination of these forecasts provided a unique opportunity to investigate the potential effect of CPI variability on the accuracy of other forecasting methods. To ensure that the case company's EAC forecast accuracy remains confidential, all EVM-based and company-derived EAC Forecast Errors are expressed as a factor of a confidential factor, A (Equation 4).

3.3 Statistical Analyses

Data were compared using an unpaired Student's t-test where indicated. Associations between variables were analyzed using Pearson's correlation coefficients, and the line of best fit was obtained through linear regression. Data are expressed as mean \pm standard error (SE), where $P < 0.05$ is considered significant.

4 RESULTS

In contrast to previous studies [Christensen and Heise (1992), Christensen and Payne (1992), and Henderson and Zwikael (2008)], none of the studied projects' CPIs were stable at 20% completion. Indeed, only 26% of projects stabilized before 60% completion point (i.e., 6% and 20% of project CPIs stabilized between 20-40% and 40-60%, respectively). The majority of the studied projects demonstrated late or no stability, as 17% and 14% of projects stabilized between 60-80% and 80-100%, respectively, and 43% never stabilized (Figure 1).

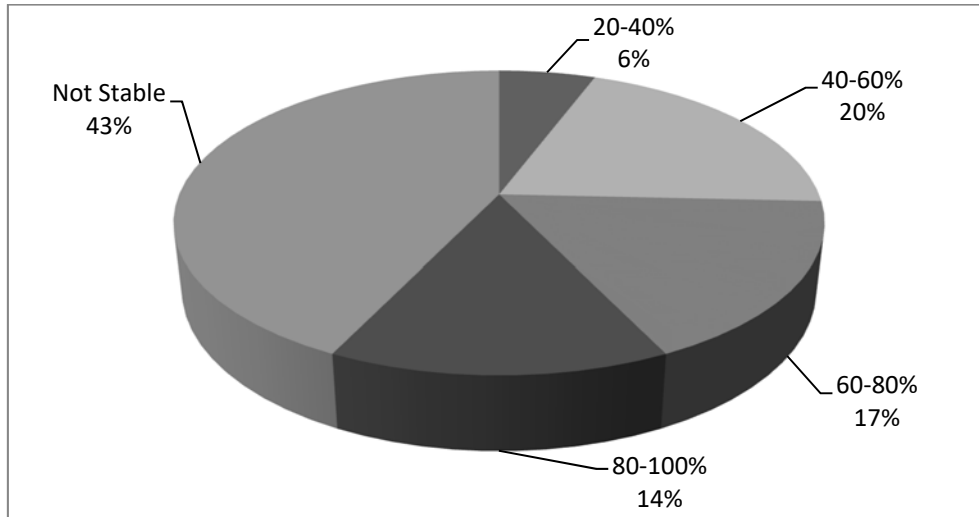


Figure 1: CPI stability point distribution of studied projects

Given the relatively late stability observed in Figure 1, CPI stability points were correlated with average EAC forecasting error to determine if CPI instability was associated with reduced forecasting accuracy. As expected from Equation 3, correlation analysis revealed a strong positive correlation between the CPI stability point and the EAC forecast error in projects where CPI stabilized prior to project completion ($r=0.63$; $n=15$, $P<0.05$; Figure 2), suggesting that CPI instability can degrade EAC forecasting accuracy. Indeed, average EAC forecasting error of projects whose CPI never stabilized ($1.48A \pm 0.13A$) was greater than projects with early stability (i.e., $<40\%$) ($0.57A \pm 0.07A$).

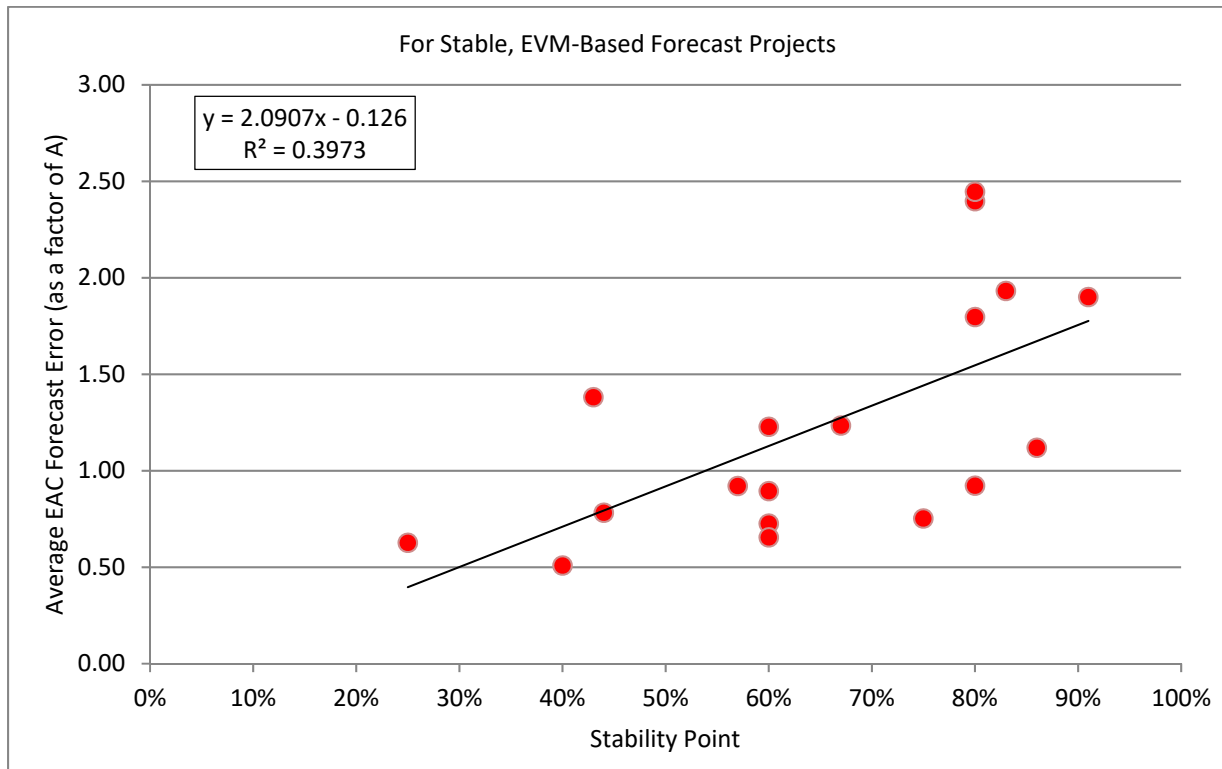


Figure 2: Correlation analysis for stable projects using EVM-based forecast

In contrast to the association of CPI stability point and EAC forecast error of EVM-based forecasting methods, CPI stability was not associated with EAC forecast error when using the company-derived forecasting method ($r=0.25$ $n=20$; Figure 3).

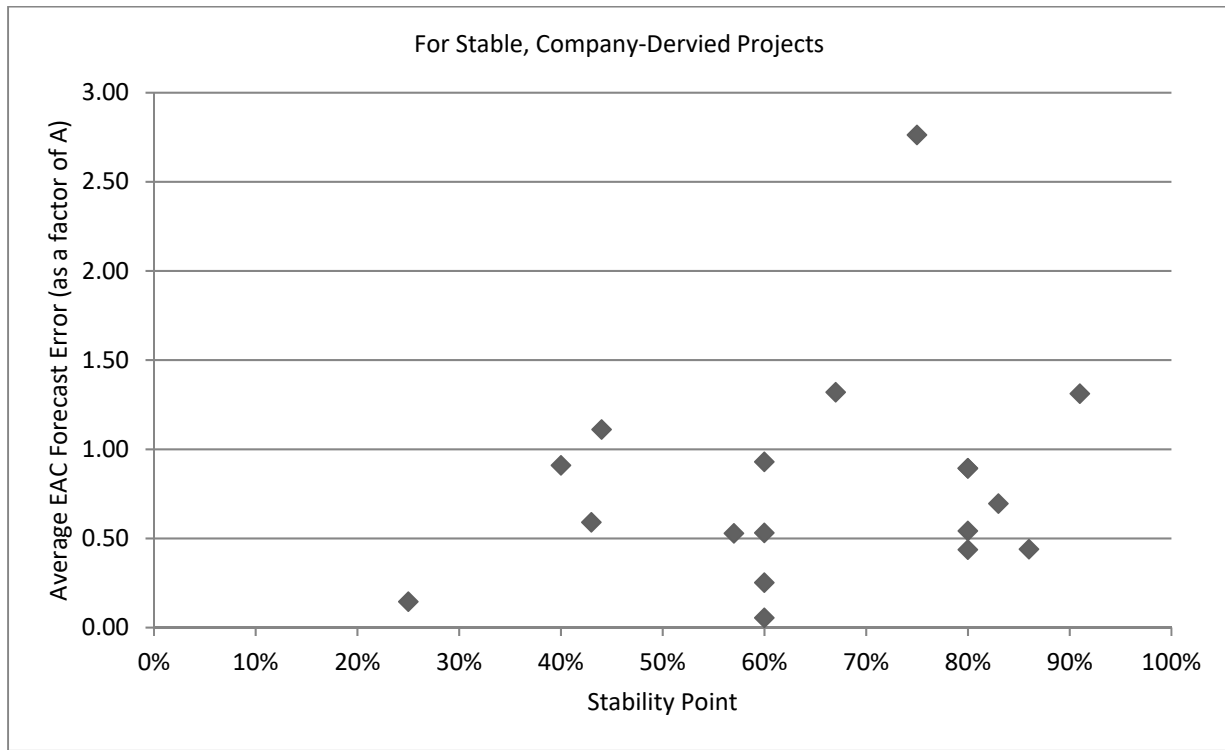


Figure 3: Scatter plot of stability point and average EAC forecast error for company-derived forecasts

While a significant difference between EVM-based ($1.48A \pm 0.13A$; $n=15$; $P<0.05$) and company-derived ($0.64A \pm 0.13A$ $n=15$) average EAC forecast errors were observed for unstable projects, differences between the average EAC forecast error for EVM-based and company-derived methods increased in projects characterized by late CPI stability (Figure 4).

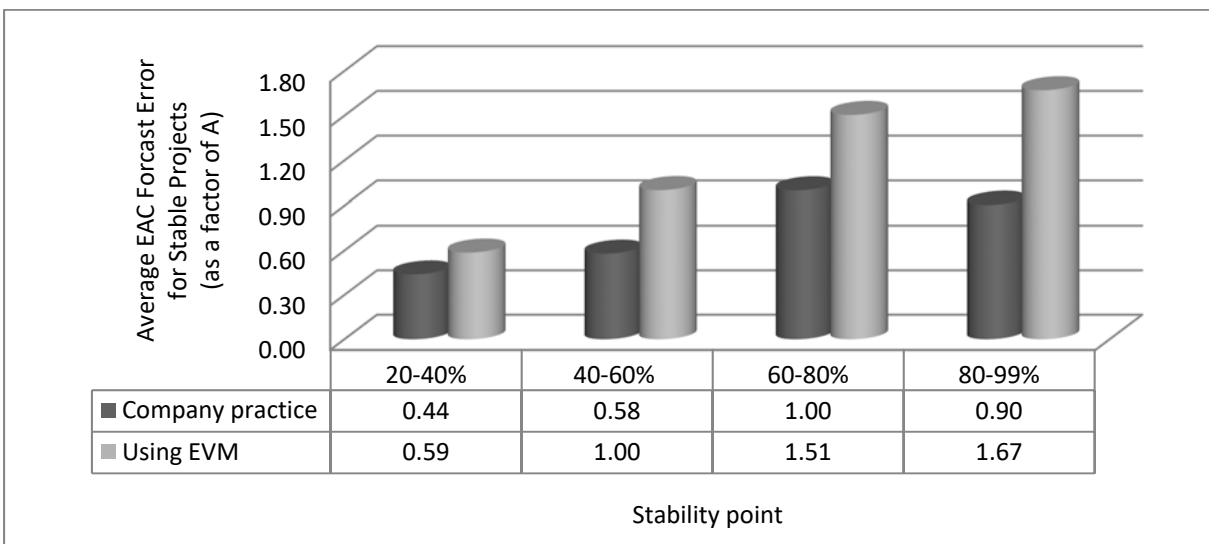


Figure 4: Relation between average forecast error and CPI stability for stable projects

5 DISCUSSION

Understanding CPI instability and its effects on EAC forecasting in industrial construction is important for practitioners who use EAC routinely. Here, CPI instability was found to degrade forecast accuracy of EVM-based forecasts. Consistent with the observations expected from Equation 3, a significant correlation between CPI-dependant forecasting method accuracy and CPI stability point was found (Figure 2), indicating that early project CPI stability is associated with the generation of more reliable project estimates. This is in contrast to company-derived methods, where no correlation was observed (Figure 3). Notably, however, projects with early stability resulted in lower average forecasting error for both forecasting methods, as demonstrated in Figure 4. EVM-based forecasts resulted in greater error (i.e., 1.48A versus 0.64A) compared to forecasts derived using the company's practice, suggesting that expert opinion and consideration of factors other than CPI can enhance the EAC forecast accuracy. Since the objective of this research is to study the relationship between forecasting methods and stability as opposed to the examination of the exact value of EAC forecasting error, errors are reported as a factor of A (i.e., a randomly selected number) to maintain company confidentiality.

6 CONCLUSION

The current study used empirical industrial project data from a contractor in Alberta to investigate CPI stability. A majority of construction projects stabilized in the late stages of the project (i.e., after 80% completion point), and less than 30% of projects stabilized before the 60% completion point. Since late stability in CPI values can increase error in EAC forecasts obtained using Equation 3, practitioners are encouraged to consider using alternative forecasting methods that consider factors other than or in addition to CPI. Relying solely on CPI to calculate EAC can result in inaccurate forecasting when project CPI is unstable. Indeed, application of expert judgement and current project performance, as was implemented in the company-derived forecasts, is expected to enhance EAC accuracy of projects characterized by low CPI stability.

Notably, the scope of this research is limited to one company, and additional, in-depth studies with larger datasets should be conducted to draw more generic conclusions about CPI stability in construction. Since this is an empirical study, it is important to note that late convergence of CPI in construction projects may be due to shortcomings in cost and/or progress reporting or delays in change management processes. With regards to forecast accuracy, factors other than CPI can result in erroneous judgement of final project cost. While CPI variation is not the only factor, it can be considered a contributing factor. Finally, studying projects in more details (e.g., for each discipline) may result in a better understanding of the sources of CPI instability.

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