

Cost Estimate at Completion Methods in Construction Projects

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Abstract. Accurate forecasting of an ongoing project cost is a major issue in project monitoring. One of the challenges faced by project managers is selection of the most accurate cost Estimate at Completion (EAC) method to improve tracking their projects. To assist in the task, a review of previous research and applications is proposed with regard to both construction and other industries. Studies are classified into conventional index-based, statistics-aided, and simulation-based cost EAC methods and summarized with characteristics and advantages. Conclusions are drawn with directions for future research emphasizing the need for construction projects to adapt methods from other experienced fields to reflect more reliable and consistent cost EAC forecasting capabilities.

Keywords: Cost, Earned Value Management, Estimate At Completion, Performance, Project monitoring, Simulation, Statistics

1. Introduction

Choosing a method to accurately estimate the cost at completion of ongoing projects based on current performance is an open issue in the area of project monitoring. A largely used technique which has been showing itself as an objective and valuable tool to accurately compute cost Estimate At Completion (EAC) is the conventional Earned Value Management (EVM) methodology with associated Cost Performance Index (CPI) and Schedule Performance Index (SPI). However, the technique has some limitations in calculating the cost EAC such as failing to address a critical path, probabilistic estimations, work quality and risk impact. Thus, application of statistical methods and simulation techniques has been considered as an attempt to overcome the limitations inherent with conventional index-based EAC.

The objective of this paper is to provide a review of conventional and refined cost EAC research with focus on construction projects. In section 2 we review some pertinent literature on the index-based, statistical-aided, and simulation-based EAC methods in various industries. Section 3 provides applications of these techniques in the construction industry. Finally, conclusions are drawn showing future research directions in the field.

2. Review of EAC methods

Many studies have been carried out to introduce various new or improved EAC techniques. For the purpose of this review, they are divided into three main categories, namely: traditional index-based, statistics-aided, and simulation-based methods.

2.1. Traditional Index-Based EAC

Originating in the 1960s, EVM has become a standard methodology to track a project status and to estimate the cost at completion based on measured actual performance against scheduled performance. Based on EVM variables (i.e.: BAC Budget at Completion, BCWS Budgeted Cost of Work Scheduled, BCWP Budgeted Cost of Work Performed, ACWP Actual Cost of Work Performed), the Project Management Institute [1] provides the following equations to compute EAC.

$$EAC = ACWP + (BAC-BCWP)/CPI = BAC/CPI \quad (1)$$

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$$EAC = ACWP + (BAC-BCWP)/(W1xCPI+W2xSPI) = BAC/(W1xCPI+W2xSPI) \quad (2)$$

$$EAC = ACWP + (BAC-BCWP)/(SPIxCPI) = BAC/(SPIxCPI) \quad (3)$$

where CPI is the cumulative BCWP to ACWP ratio, SPI the cumulative BCWP to BCWS ratio, $W1xCPI+W2xSPI$ Composite Index (CI), and $SPIxCPI$ is termed as Critical Ratio (CR).

Eq. (1) implies that current cost performance will continue until the end of a project with no changes, while the other two equations assume that future cost performance will be subject to changes and influenced by past schedule delay. Particularly, Eq. (2) states that EAC is affected in some proportion by CI where CPI and SPI are assigned complementary weights ($W1$ and $W2$) that normally add to 1.0. A ceiling EAC is computed by Eq. 3 where additional cost is likely to be spent to recover any schedule delay.

According to Lipke *et al.* [2], EAC is computed with Eq. (4) because the cumulative CPI stabilizes by the time the project is 20 percent complete within a range of 0.10 from that value ($CPI_{20\%}$), and in most large projects it tends to worsen from the point of stability until the project completion.

$$EAC = BAC/(CPI_{20\%} \pm 0.10) \quad (4)$$

Overall, it has been shown that these research results are well applicable to defense and defense software projects with long durations and large-sized budgets.

2.2. EACs with Statistical Tools

Statistical techniques try to overcome limitations of index-based methods and to improve accuracy of EAC forecasting. Some of advantages of the statistical approach are a proper addressing of quality of project execution, probabilistic estimations, undefined scope of work, and risk impact.

Christensen *et al.* [3] reviewed a considerable number of previous studies on EAC research carried out by different scholars from 1973 to 1989 in the areas of both index-based and statistics-aided methods. Most index-based EAC studies proposed ways to develop weights for computing Composite Index, while methods based on the complex nonlinear regression analysis were analysed to see if they could prove better predicting abilities. Overall, the authors concluded that the accuracy of regression-based models over index-based formulas was not established. Following is a list of more recent continued research works.

For instance, Druker *et al.* [4] propose a new method with statistical analysis techniques applied to index-based EAC. According to authors one of limitations of estimates developed using the simple index-based formula is that the S-curve of EAC is subject to tail-chasing whenever CPI changes throughout the life of a project. Tail-chasing happens when EAC of an overrunning project systematically lags in predicting the extra cost. Their approach overcomes this problem because it relies on historical data and is thus testable (can be subjected to statistical significance tests), that is defensible. Cost EAC produced using this technique was unbiased and the descriptive statistics developed as a byproduct of the method will allow uncertainty to be quantified for risk analysis purposes. And, because this method normalizes out shifts in CPI that seem to be pervasive among similar projects, cost trend can be monitored with a high degree of accuracy.

Other studies were conducted to improve the performance of Earned Value Management by introducing Statistical Process Control (SPC) techniques. With regard to software projects, Lipke [5] implements SPC charts into EVM. The approach provides distinction between normal and anomalous behaviour of CPI data. Control charts act as a filter establishing upper and lower thresholds within which CPI behaviour is monitored. Wang *et al.* [6] emphasize an importance of integrating SPC into EVM because EVM appears to be too sensitive to detect abnormal signals of software projects. Any large variance between Earned Value and Planned Value (or Actual Value) is considered as an abnormal signal. Because the distribution of CPI generally follows the normal distribution, applying SPC to CPI is more reasonable. First, it reduces the complexity of project state judgment. The SPC provides a set of statistical rules to detect abnormal signals and can simply be used to judge whether cost of a project is out of control. Second, it minimizes the cost of measure and analysis; most false alarms (which CPI is not equal 1.0 exactly, but fall into the limits) are filtrated. The approach was applied in more than 30 organizations resulting in significant reducing of complexity and cost of measurement, and most of warning points were identified effectively without disturbing of false alarms.

The approach suggested by Lipke *et al.* [2] made use of a well-established statistical mathematics to improve forecasting capabilities of EVM. The statistical analysis of predicted upper and lower bounds for a project cost shows generally reliable performance of the proposed method regardless of chosen confidence level. It was seen that increasing the confidence level resulted in high probability that assures reliable limit bounds. At the 98% confidence the analysis showed a comparatively accurate forecasting beginning as early as at 10% project completion while using the 90% confidence proved reliable prediction of upper and lower bounds beginning at 60% completion. Due to the unique characteristics of the data related to software projects, it was postulated that 90% confidence is appropriate for most circumstances.

Anbari [7], with regard to software projects, proposes an insight to EVM method providing a simple control limit for CPI, SPI, and Critical Ratio monitored through the so-called “Traffic Light” approach where the green light goes to indices above 1.0 indicating good performance; yellow light from 1.0 to 0.8, and the red light to underperforming indices below 0.8. A graph of cost EAC, built by considering the CPI behaviour extracted from the Traffic Light control chart provides a valuable indicator of trends in project cost performance and the impact of any corrective actions.

2.3. Simulation-based EAC methods

Simulation techniques are regarded as an alternative approach to both index-based and statistics-aided methods. This approach is of valuable use during the early stages of the project execution when conventional methods might fail to accurately predict EAC due to missing cost information and the effects of early risks and uncertainty [8]. Thus, the application of simulation tools to EAC forecasting enables to make more informed decisions when setting or adjusting a project cost baseline.

According to Hillson [9], computing EAC with performance indices does not take explicitly into account the effects of future risks and, thus, he proposes integrating risk management and EVM. He suggests allocating a risk-balanced cost contingency, which can be determined with risk assessment methodologies, to the project baseline in order to cover the expected level of risk in the remaining portion of the job. To this end, Monte Carlo simulations are performed to set risk-adjusted revised budgets and define risk-based S-curve lines of expected expenditure to completion. Vargas [10] also applies Monte Carlo simulations based on probabilistic indices. Unlike the traditional EAC method which provides deterministic estimates, his approach contributes to probabilistic vision of the final cost elaborated for a project. In particular, the simulation defines the three main indices, namely Budgeted Cost Index, which is usually set at 1, CPI, and Critical Ratio that form the triangular distribution of cost EACs – optimistic, most likely and pessimistic forecasts respectively.

Zawistowski [11] modifies traditional approach through utilization of Monte Carlo simulations and the fuzzy logic theory in the form of introducing linguistic variables. The analysis aims at more complex and accurate risk assessment of a project. The use of the Monte Carlo simulation gives an opportunity to analyse a broader spectrum of data in the form of probability distributions of cost EAC. Further, in order to minimize possible errors related to wrong probability variables, distributions were defined through application of fuzzy linguistic variables. Introduction of these variables significantly enhances the process of defining probable course of a project, leading to more accurate prediction of the final cost. The research steps include the process of fuzzification that consists in transforming crisp values (related to the Monte Carlo probability distributions) into grades of membership for linguistic terms of fuzzy sets, and, finally, the process of defuzzification, leading to more accurate quantifiable results.

Overall, the literature reviewed in this paper shows that the advanced methods (improved linear index, nonlinear regression, simulation techniques etc.) for cost EAC of ongoing projects have been largely explored and effectively implemented mostly in large-sized defense, product development, and software projects.

3. EAC Methods in the Construction Industry

With purpose of effective monitoring and timely cost and schedule adjusting, construction project managers use the practical index-based techniques to predict the final cost. However, one should pay careful attention when selecting and applying index-based metrics that depend on project type and development

stage. In fact, performance monitoring assumes that cost reporting and network scheduling are prerequisites for accurate EAC. Many small projects do not satisfy either of these prerequisites and collection of timely and reliable actual cost data [12]. Moreover, construction projects often require that index-based EAC methods are tailored to fit characteristics of continuous activities that cannot be easily broken down into small work packages, and to take into consideration the impact of multiple-path tight schedules. Thus, the index-based approaches that are applicable to complex projects with long durations and large-sized budgets fail to be easily adopted for smaller or construction projects.

This section presents some of statistical and simulation tools that were applied to construction projects. For example, Nassar *et al.* [13] apply Weibull analysis to stochastically evaluate the schedule performance of construction projects by using a dataset of CPI and SPI. Collection of percent-complete data, mean, standard deviation, and range and ranking of both SPI and CPI are drawn for building the Weibull distribution. The approach provides three advantages over traditional method. Firstly, since CPI and SPI are essentially performance measures, the robustness and flexibility of the Weibull distribution in modelling performance characteristics can be used effectively to model performance indices. Secondly, scale and shape parameters of its probability density function represent meaningful measures of the data at hand. And, finally, the approach provides accurate performance analysis and risk predictions with a small sample.

Leu and Lin [14] state that index-based EAC may cause some project managers to ignore the information that can come from performance variations of their construction projects with associated causes and effects. Their research attempts to improve the traditional EVM forecasting ability by application of Statistical Process Control (SPC) charts to distinguish variations in performance indices. The chart consists of a central line and upper and lower control limits. If all CPI and SPI data are plotted within the control limits and without any particular tendency, the process is regarded as being under control. A comparative analysis between traditional EVM and the new approach is then undertaken to identify the effectiveness of the latter one. Finally, the characteristic-based performance pattern correction model gives project managers a practical tool to assess the likelihood of performance indices pattern at initial project stages.

Barraza *et al.* [15] use stochastic S curves (SS-curves) as an alternative way to deterministic index-based S-curves. The SS-curve is generated by simulation and is based on the defined variability in cost of individual activities within Work Breakdown Structure (WBS). The uniqueness of this approach is that it provides probability distributions of the cost required to complete the project at every desired point in time. EAC is defined by comparing BCWS with the expected forecasted final cost. The SS-curve technique allows calculating cost EAC objectively without limitations associated with deterministic estimation. The concept of probability of this approach allows one to more accurately estimate the cost at completion.

Another simulation-based approach to EAC is to use System Dynamics [16]. With this practicable methodology, De Marco and Rafele [17] developed a model to forecast EAC based on feedback loops that typically affect project performance. The simulation computes EAC after a modeller sets a few input variables, such as change orders, procurement delays and level of resources, which affect or even obliterate the initial budgets and schedules, thus requiring costly rework and additional resource procurement.

In conclusion to this section, it is worthwhile to summarize that the usage of index-based EAC in the field is certainly a good and practical way to forecast cost EAC, but this approach does not work properly when construction projects are complex in structure and dynamic by nature. Moreover, it appears that little research has been carried out to refine index-based approaches and the field applications carries scenarios nature, not systematic and well established.

4. Conclusions

Methods for cost EAC of ongoing projects in other industries have been largely explored. There are variety of refined traditional, statistics-aided, and simulation-based EAC forecasting techniques for large and complex defense, product development, and software projects and very little research has been done in context of construction projects.

The research reveals that the construction industry is lagging behind other industries and has difficulties in adequately importing advanced statistical and simulation tools that can help project managers to undertake

more precise and effective control actions with integrated information related to future uncertainty. The construction industry needs to adopt the advanced methods developed by other experienced industries in order to integrate relevant information and uncertainties into construction project performance predictions.

To this end, future directions in cost EAC research in the filed should be addressed to support this innovation process. On the one hand, refined methods have to be developed while keeping a reasonable level of viability and practicability. On the other hand, implementation and application of new methods are suggested to assist project managers in the task of selecting and implementing the appropriate EAC method, and finally to prove the value that a more accurate forecasting model enables project teams to better control tight budgets and schedules.

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