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Time series-based Project Cost Forecasting Framework

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Abstract

Current inflation rates have significantly been increasing construction project costs globally. Thus, it is crucial to consider potential inflationary trends when estimating the cost at completion of prolonged projects. However, the absence of literature providing guidance on analyzing inflation trends and adjusting the ongoing project cost performance factor is a gap that needs filling. This study proposes a framework for estimating ongoing project costs based on trend and seasonality analysis of the project cost performance through the Holt-Winters method. The proposed framework also incorporates the estimation of project completion time and is applied to a real case study to assess its efficacy. The results are compared with the ones obtained through pre-existing index-based methods. This paper seeks to improve the accuracy of project cost estimation and management in challenging and uncertain economic environments by providing an alternative to the traditional cost at completion forecasting approach.

Keywords: Estimate at Completion; Time Series Analysis; Project Monitoring

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1. Introduction

Construction projects are subject to numerous factors that can affect cost, including materials price fluctuations, project scope changes, unforeseen circumstances and economic conditions [1]. For example, the recent pandemic-related complications and inflation have introduced an additional layer of complexity to cost estimation [2,3]. Furthermore, restrictions and disruptions have amplified the uncertainty of project planning and execution, rendering it difficult to precisely evaluate the impact of these factors [4,5].

Thorough evaluation of the revised cost estimates is imperative for effective project management. Accurate and precise projections enable project managers to identify possible cost overruns and make the required adjustments to ensure that the project stays within budget. Nonetheless, the present literature on cost estimation, which relies on the Earned Value Management (EVM) methodology [6,7], has limitations. Specifically, its formulae are predicated on specific assumptions, none of which accounts for possible variations in project cost performance over time. The lack of a reliable method for projecting cost escalation over an extended period poses a significant challenge for projects with prolonged durations. Inflationary pressures can potentially compromise the cost performance of such projects, making it crucial to find effective solutions to mitigate this risk.

This study presents a novel framework for estimating a project cost at completion via a joint cost and schedule analysis. The framework integrates the EVM and Earned Schedule (ES, [8]) methodologies, enabling the assessment of project performance using data related to cost, schedule, and work completed. To project cost performance, the framework employs the Holt-Winters method [9,10], a statistical technique utilized for time-series forecasting. The EVM cost index is utilized to express cost performance, which is then projected using the Holt-Winters method.

To assess the effectiveness of the framework, a real engineering and construction project is used as a case study. The framework results are compared to the methods proposed in the literature, and the comparison reveals that the framework can account for schedule performance without generating excessive forecasts. By employing this framework, professionals can evaluate project costs and anticipate potential issues, even in uncertain economic conditions, by analyzing the project cost performance trend. This, in turn, enables more effective management of project budgets and resources, leading to better outcomes.

The paper is organized as follows. Section 1 introduces the scope and purpose of the study. Section 2 provides an overview of attempts to extend the traditional EVM. The research methodology is described in Section 3, where the proposed framework based on EVM and ES methodologies is presented. In Section 4, the framework is applied to a case study, and the results are compared to other index-based methods from the literature. Section 5 summarizes the conclusions drawn from the study, highlighting the importance of cost and schedule integration, and forecasting for effective project management. Finally, an outlook for future research in the area is provided.

2. Literature Analysis

The literature on models for estimating project cost at completion is extensive and can be broadly categorized into two groups: those based on the EVM methodology and those based on regression analysis [11]. The primary difference is that EVM-based studies focus on analyzing internal project variables, while regression-based studies incorporate empirical analysis of external data to characterize the evolution of project costs. Given the scope of this study, this literature review primarily focuses on index-based models for cost estimation.

In EVM-based models, the project cost estimate at completion ($cEAC$) is determined by adding actual cost to date (AC) and the estimate-to-complete (ETC). The ETC is calculated by dividing the difference between the budget at completion (BAC) and the earned value (EV), which measures the work performed in terms of currency, by the cost performance factor (cPF). Equation 1 illustrates the relationship between $cEAC$, AC, ETC, BAC, EV, and cPF.

$$cEAC(t) = AC(t) + ETC(t) = AC(t) + [BAC - EV(t)]/cPF(t) \tag{1}$$

To gain a better understanding of the differences between cost performance models in the literature, it is necessary to consider the variables used to determine cPF. Table 1 provides a summary of several studies that analyzed different indicators as cPF. Overall, all cPFs assume that, from the actual time until the project completion, the project cost performance is not going to change. Specifically, a cPF of 1 implies that cost overruns are not expected to propagate in the future. The indicators CPI, SPI^{EVM}, and SPI^{ES} will be described in detail in the Methodology section. Regarding the parameters w and $(1-\mathrm{w})$, they indicate the CPI and SPI weights in the weighted sum. Finally, cPF_{X} represent the mean of the respective indicator over the last X periods.

Table 1. Literatures studies addressing cPF assessment.

Reference	cPF									
	1	CPI	SPI^{EVM}	SPI^{ES}	$CPI \cdot SPI^{\mathrm{EVM}}$	$CPI \cdot SPI^{\mathrm{ES}}$	$\mathrm{w}CPI + (1-\mathrm{w})SPI^{\mathrm{EVM}}$	$\mathrm{w}CPI + (1-\mathrm{w})SPI^{\mathrm{ES}}$	CPI_{X}	$CPI_{\mathrm{X}} \cdot SPI_{\mathrm{X}}^{\mathrm{EVM}}$
[12]	✓	✓			✓					
[13]	✓	✓			✓		✓			
[14]	✓	✓			✓					
[15,16]	✓	✓			✓		✓		✓	✓
[17]		✓	✓		✓		✓		✓	
[18]		✓								
[19]	✓	✓	✓		✓					
[20]	✓	✓	✓	✓	✓	✓	✓	✓		
[21]		✓			✓					
[22]		✓			✓					
[23]		✓	✓		✓					
[24]		✓			✓					
[25]	✓	✓			✓					
[26]		✓			✓		✓		✓	

In this study, we present a novel approach to estimate the cost performance index, $\widehat{CPI}(t)$, by employing the Holt-Winters method. This method has been shown to be effective in performance forecasting when the factor being analyzed displays both trend and seasonal behavior [27]. Previous studies have investigated the use of other smoothing techniques in project control contexts, such as exponential smoothing and moving averages [27–31]. Other studies have moved from simple techniques to more sophisticated models, such as autoregressive integrated moving average and Holt-Winters, to analyze cost indexes, such as [32–34].

3. Methodology

Let t denote the tth time unit, where $t = 0$ represents the start date, $t = \mathrm{PD}$ the planned duration, and $t = AD$ represents the actual duration.

Let dWS and dWP denote the percentage of marginal work scheduled and performed, respectively. Multiplying dWS and dWP by the project budget at completion, BAC, allows to determine the marginal planned value, $dPV(t) = dWS(t) \cdot \mathrm{BAC}$, and marginal earned value, $dEV(t) = dWP(t) \cdot \mathrm{BAC}$, respectively. Equation 1 defines the project planned value, PV, as the cumulative sum of dPV from the project start, $t = 0$, to time t.

$$PV(t) = \sum_{i=0}^{t} dPV(i) \tag{2}$$

Similarly, Equation 2, defines the project earned value, EV, as the cumulative sum of dEV over the same period.

$$EV(t) = \sum_{i=0}^{t} dEV(i) \tag{3}$$

Equation 3 outlines the relationship between the project BAC, dPV, PV, dEV, and EV.

$$BAC = \sum_{t=0}^{PD} dPV(t) = PV(PD) = \sum_{t=0}^{AD} dEV(t) = EV(AD) \tag{4}$$

Let dAC and AC indicate the project marginal and cumulative actual cost, respectively, which relationship is described by Equation 4.

$$AC(t) = \sum_{i=0}^{t} dAC(i) \tag{5}$$

3.1. Cost Estimate at Completion

While Equation 1 provides the project cost estimate at completion, $cEAC$, this study proposes an alternative approach to compute the ETC. Specifically, ETC is calculated by summing up the marginal actual cost estimate, $\widehat{dAC}$, from the succeeding time unit, $t+1$, until the project time estimate at completion, $tEAC$, as per Equation 6.

$$ETC(t) = \sum_{i=t+1}^{tEAC(t)} \widehat{dAC}(i) \tag{6}$$

3.2. Time Estimate at Completion

The EVM and ES methodologies provide three distinct methods to determine the $tEAC^{m}$, denoted as, m.

3.2.1. EVM Method

As per the EVM methodology, the $tEAC^{\mathrm{EVM}}$ is derived using the ratio of PD to the EVM schedule performance index, SPI^{EVM}. The SPI^{EVM} is in turn calculated using the ratio EV to PV. Equation 7 provides the relationship between $tEAC^{\mathrm{EVM}}$, SPI^{EVM}, EV, and PV.

$$tEAC^{EVM}(t) = PD/SPI^{EVM}(t) = PD/[EV(t)/PV(t)] = PD \cdot PV(t)/EV(t) \tag{7}$$

3.2.2. ES Method

There are two distinct approaches within the ES methodology for computing the project $tEAC^{\mathrm{ES}}$.

3.2.2.1. ES-SPI Approach

In the first approach, similarly to the EVM one, the $tEAC^{\mathrm{ES-SPI}}$ is derived by dividing PD by the ES schedule performance index, SPI^{ES}. In turn, SPI^{ES} is determined through the ratio of the project earned schedule, ES, to actual time t. Equations 8 and 9 provide the calculation of the ES metric through linear interpolation of the project PV.

$$ES(t) = x(t) + \{EV(t) - PV[x(t)]\}/\{PV[x(t)+1] - PV[x(t)]\} \tag{8}$$

$$x(t) = \{j : EV(t) \geq PV(j),\ EV(j) < PV(j+1)\} \tag{9}$$

Equation 10 provides the relationship between $tEAC^{\mathrm{ES-SPI}}$, SPI^{ES}, ES, and t.

$$tEAC^{ES-SPI}(t) = PD/SPI^{ES}(t) = PD/[ES(t)/t] = PD/ES(t) \cdot t \tag{10}$$

3.2.2.2. ES-SV Approach

In the second approach, ES-SV, the $tEAC^{\mathrm{ES-SV}}$ is obtained by subtracting the ES schedule variance, SV^{ES}, from PD. In turn, SV^{ES} is obtained by subtracting the actual time t from ES. Equation 11 denotes the relationship between $tEAC^{\mathrm{ES-SV}}$, SV^{ES}, ES, and t.

$$tEAC^{ES-SV}(t) = PD - SV^{ES}(t) = PD - [ES(t) - t] = PD - ES(t) + t \tag{11}$$

3.3. Marginal Actual Cost Estimates

Equation 12 expresses the calculation of the marginal actual cost estimate, $\widehat{dAC}$, as a function of $\widehat{dEV}$ and the cost performance index estimate, $\widehat{CPI}$. Specifically, $\widehat{dAC}$ is computed as the ratio of $\widehat{dEV}$ to $\widehat{CPI}$.

$$\widehat{dAC}(t) = \widehat{dEV}(t)/\widehat{CPI}(t) \tag{12}$$

3.4. Marginal Earned Value and Earned Value Estimates

The marginal earned value estimate, $\widehat{dEV}^m$, is given by the difference between the EV estimate at time t, $\widehat{EV}^m(t)$, and the one referring to the previous time unit, $\widehat{EV}^m(t-1)$, as per Equation 13.

$$\widehat{dEV}^m(t) = \widehat{EV}^m(t) - \widehat{EV}^m(t-1) \tag{13}$$

To estimate the earned value, $\widehat{EV}^m$, we perform an affine transformation of the PV curve segment that is limited to the time interval between ES and the project PD. This is done by fixing the EV values but changing their t coordinates, so that $\widehat{EV}(t') = PV(t)$, where t' is given by Equation 14.

$$t' = AT + (t - AT) \cdot [tEAC^m(t) - AT]/(PD - AT) \tag{14}$$

Equation 14 allows to determine $\widehat{EV}^m(AT) = EV(AT)$, and $\widehat{EV}^m[tEAC^m(t)] = PV(\text{PD})$, as per Equation 3.

3.5. Cost Performance Index

In traditional EVM, $\widehat{CPI}$ is assumed to be constant and equal to the current CPI, which is calculated by taking the ratio EV to AC, as per Equation 15.

$$\widehat{CPI}(j > t) = CPI(t) = EV(t)/AC(t) \tag{15}$$

To account for potential changes in the CPI in the future, the Holt-Winters additive model, presented Equation 16, is utilized to estimate the $\widehat{CPI}$. The model is based on three variables, each with its own smoothing factor: the level component, $L(t)$, with weight α (Equation 17); the trend component, $T(t)$, with weight γ (Equation 18); and the seasonal component, $S(t)$, with weight δ (Equation 19). The initial values of $L(0)$ and $T(0)$ are determined through linear regression on time t, while $S(0)$ is estimated from a dummy-variable regression using detrended data.

$$\widehat{CPI}[t + tEAC^m(t) - PD] = L(t-1) + [tEAC^m(t) - PD] \cdot T(t-1) + S(t-p) + [tEAC^m(t) - PD] - p \tag{16}$$

$$L(t) = \alpha[CPI(t) - S(t-p)] + (1-\alpha)[L(t-1) + T(t-1)] \tag{17}$$

$$T(t) = \gamma[L(t) - L(t-1)] - (1-\gamma) \cdot T(t-1) \tag{18}$$

$$S(t) = \delta[CPI(t) - L(t)] + (1-\delta) \cdot S(t-p) \tag{19}$$

where p is the season period, to be determined through exploratory data analysis of the CPI series.

4. Case Study

The framework is applied to a real engineering and construction project. To protect source anonymity, both schedule-related and time-related variables are scaled following [11]. Specifically, time t is expressed relative to the project PD (i.e., $t = t/\text{PD}$). Similarly, both BAC and $AC(t)$ are expressed relative to BAC.

The time unit at which the review took place is $AT = 0.825$. While $PV = .928$, $EV = .727$, and $ES = .508$, hinting at a schedule delay. The current EVM and ES schedule performance indexes are respectively $SPI^{\text{EVM}} = 0.7831$ and $SPI^{\text{ES}} = 0.6157$, while the ES schedule variance is $SV^{\text{ES}} = -0.3176$. Calling Equations 7 and 10 allowed to determine $tEAC^{\text{EVM}} = 1.2769$ and $tEAC^{\text{ES-SPI}} = 1.6243$, respectively. Instead, calling Equation 11 provides $tEAC^{\text{ES-SV}} = 1.3171$.

Concerning the cost performance, the $CPI(t)$ shows a decreasing seasonal trend, with season period p = 4. Applying the Holt-Winters method with arbitrary parameters α = γ = δ = 0.2 allowed to project $\widehat{CPI}(t)$ from $AT = 0.825$ to $\max\{tEAC^{\text{EVM}}, tEAC^{\text{ES-SPI}}, tEAC^{\text{ES-SV}}\} = 1.6243$. Figure 1 provides the CPI forecasts.

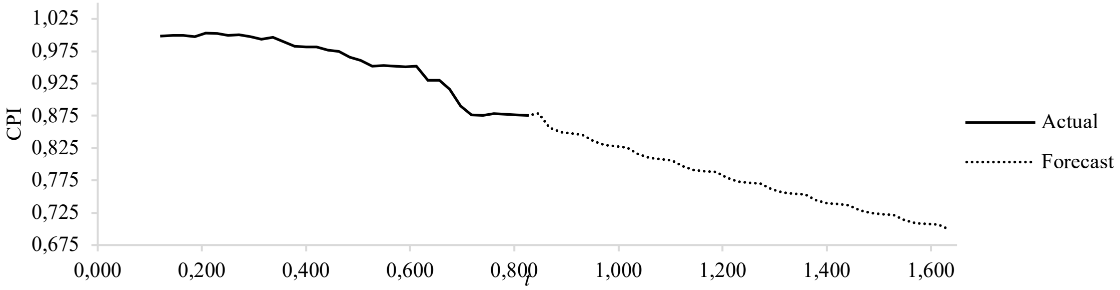

Fig. 1. Cost performance index actual and forecasted values.

Following Equations 13 and 14 allows to determine the $\widehat{dEV}^m$ for each m method. Calling Equation 12 first to evaluate $\widehat{dAC}^m(t)$ and then Equation 4 allows to evaluate the actual cost cumulative curve, as of Figure 2.

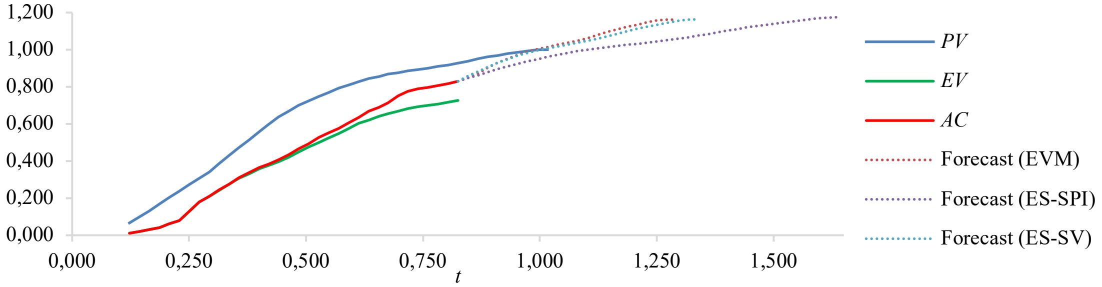

Fig. 2. Project cumulative planned value, earned value, actual cost, and actual cost estimate curves.

Due to the longer forecast, the cost estimate at completion mirrors by the m method mirrors the respective schedule estimate at completion, i.e. $cEAC^{\text{ES-SPI}} = 1.1749 > cEAC^{\text{ES-SV}} = 1.1633 > cEAC^{\text{EVM}} = 1.1621$.

The different estimates are compared in Table 2. The weight w was arbitrarily set to .8. Instead, the parameter X was set equal to p, hence 4. Results show that the cost estimates at completion are in line with the ones of the CPI, $.8CPI + .2SPI^{\text{EVM}}$ and CPI_4. On the other hand, all other methods, which weight schedule performance more, provide higher $cEAC$s. By considering the comparison results in Table 2, it can be inferred that while schedule performance may impact cost performance, incorporating SPI^{EVM} or SPI^{ES} without appropriate weighting in the EVM $cEAC$ formulation may result in excessive forecasts. In contrast, the proposed method provides a more balanced estimate, which is consistent with the CPI-based $cEAC$s.

Table 2. Different approaches' results to compute project $cEAC$.

Approach	Method	$tEAC$	$cEAC$
$AC(t) + [\text{BAC} - EV(t)]/cPF(t)$	1		1.103
	CPI		1.142
	SPI^{EVM}		1.277
	SPI^{ES}		1.624
	$CPI \cdot SPI^{\text{EVM}}$		1.458
	$CPI \cdot SPI^{\text{ES}}$		1.855
	$.8CPI + .2SPI^{\text{EVM}}$		1.167
	$.8CPI + .2SPI^{\text{ES}}$		1.214
	CPI_4		1.140
	$CPI_4 \cdot SPI_4^{\text{EVM}}$		1.416
$AC(t) + \sum_{i=t+1}^{tEAC(t)} \widehat{dAC}(i)$	EVM	1.277	1.162
	ES − SPI	1.624	1.175
	ES − SV	1.317	1.163

5. Conclusions

This study introduces a comprehensive framework for predicting the final cost of a prolonged project. The framework calculates the cost at completion by summing the actual cost incurred to date (AC) and the estimate-to-complete (ETC). Unlike the EVM methodology, the framework forecasts the marginal cost ($\widehat{dAC}$) from the current time to the estimated completion date ($tEAC$). This is achieved by multiplying the adjusted workload ($\widehat{dEV}$) by the forecasted cost performance index ($\widehat{CPI}$). The framework recommends analyzing the CPI as a time-series and projecting the index using the Holt-Winters additive model.

The study applies the framework to a real ongoing project, serving as a case study to compare the output of different $cEAC$ models reviewed in the literature. As the project has not yet been completed, it was not possible to evaluate and compare the performance of the different approaches directly. Nevertheless, it is important to highlight that the estimates obtained from the framework align with approaches that do not fully incorporate the schedule index in project cost performance evaluation, or only include it to a limited extent. Utilizing the framework offers the advantage of not depending on the assumptions made by traditional methods, and it effectively mitigates sudden fluctuations in project performance by analyzing the time series, including trend and seasonality exhibited by the CPI.

This paper's contribution to the body of knowledge is significant as it introduces an innovative approach by applying time-series forecasting to analyze cost performance behavior trend and seasonality in predicting project cost estimate at completion. Specifically, it is the first study to employ time-series forecasting to model cost behavior in project management, demonstrating the potential for improving the accuracy and reliability of project cost forecasting. Consequently, this research expands the knowledge base in project cost estimation and is a valuable resource for project managers seeking to enhance project performance.

In terms of future research, there is an opportunity to explore alternative time series forecasting methods on the same project data. This will allow researchers to determine which method yields the most accurate predictions of cost performance behavior trend and seasonality. Additionally, there is potential to apply artificial intelligence (AI) techniques to predict cost performance patterns based on past project data. Specifically, this would involve training an AI model to recognize patterns in historical cost data and utilize this information to predict future costs. Such research could further enhance the accuracy and reliability of project cost forecasting, ultimately benefiting project managers and stakeholders.

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