Using Earned Value Management with exponential smoothing technique to forecast project cost

Mengyuan Zhao¹*, Xuemin Zi²
¹School of science, Tianjin University of Technology and Education, Tianjin, Tianjin, 300222, China
²School of science, Tianjin University of Technology and Education, Tianjin, Tianjin, 300222, China
*E-mail: rkchp@zhobk.cn

Abstract. Earned value management (EVM) is developed for cost management and is widely used to evaluate and forecast project cost. Through earned value management, we can calculate the deviation between cost and schedule, as well as performance indicators such as cost performance index (CPI), schedule performance index (SPI) and duration performance index (DPI), and then predict project cost, schedule and duration. However, it is often not comprehensive to rely only on EVM for project prediction, because the project in the next testing period is not necessarily invariable and similar to the previous activities, but dynamic and flexible, and has some correlation with the previous project activities. Therefore, the research method of this paper is to combine the well-known earned Management (EVM) with the mature exponential smoothing technique to simulate the actual data of 32 simulation projects and predict the final cost of the project. After comparing the prediction results with the results of tens of thousands of simulation experiments, the final research results show that the combination of cost performance index (CPI) from earned Management (EVM) and simple exponential smoothing technique have promising performance for the final cost estimation of the project.

1. Introduction
In the actual implementation of projects, there are always some uncertainties, which lead to that if some corrective measures are not taken for some aspects in the future, the project will cannot be controlled (Armstrong 2002) [1]. So in the beginning or implementation process of the project, it may be beneficial and harmless for the organizers to predict the project. For the management, they often expect to pay more attention to the large deviation, but not to the small deviation. Earned value management (EVM) is a method to help managers select the activities that need the most attention, and track and control these activities with large deviation, so as to make the project return to the normal track (Anbari, 2003) [2].

Earned value management (EVM) is a distinguished management system integrating cost, schedule and technical performance[3]. It is widely used in calculating cost and performance indicators, and predicting the cost at completion. The project manager can carry out the next work according to the early indicators of the project performance, whether going on the current process or taking some corrective measures or others. In other words, the project manager and the project team can predict the project deviation according to the performance indicators, so as to make actions.

For decades, the project management team has made a lot of efforts and attention to the prediction of project duration, but less to the prediction of project cost. Such as moving average, exponential...
smoothing and fuzzy time series can be reasonably used to predict the performance index of the next stage of the project. The success of a project, not only need to spend less time, to ensure the quality at the same time as much as possible to reduce the final cost. Recently, Narbaev and Marco (2012) proposed the method of combining nonlinear regression and earned schedule (ES) to predict the final cost of a project [4]. Huang et al. (2014) only used EVM to predict the cost of a project [5].

Based on the project duration forecasting using earned duration management with exponential smoothing techniques proposed by Khamooshi & Abdi (2016), the earned duration index (EDI) is combined with exponential smoothing technologies to predict the final total duration of the project [6]. Because the exponential smoothing technology is used when the trend and average value change slowly with time, this paper combines CPI from EVM with exponential smoothing technology to predict the final cost of the project. The main purpose of this paper is to combine EVM and exponential smoothing technology as a new model to predict project cost, and compare the real final results with the simulation results of tens of thousands of times, and conclude that this model is promising method for prediction. In addition, the actual project data is used to test the project in multiple stages of completion.

Therefore, the arrangement of the article is as follows. After the introduction, the relevant notations and methods are presented, Then, the percentage of the root mean square error and the simulated final actual value is used to evaluate the prediction model. In the next section, a new prediction method is applied to the actual data, and the results are analyzed. Finally, the conclusion is given.

2. Notations description and method introduction

In this section, we will briefly introduce the notations used in this paper. For more details about EVM method, the reader is referred to Anbari (2003) [2].

PV, which represents the planned value of the project, is the project cost baseline. As shown in Figure 1:

![Figure 1. Conceptual chart of earned value management.](image)

AC, the actual cost of the project. In EVM, the cost performance index can be expressed as: CPI = EV / AC.
EV, the cumulative earned value up to a certain point in time, its curve represents the cumulative cost of the work completed as per planned value at a given point in time. One of its simplest calculation methods is to multiply the planned value of the project by the percentage of completed projects, that is
\[ EV = PC \times PV, \]
where PC represents the proportion of completed projects. For example, a project can be completed in 10 days with a plan value of 1000 RMB, and the actual work cost 600 RMB after 5 days. In this project, 1000 RMB refers to PV, AC is 600 RMB, and EV, which equals to \( 5 / 10 \times 1000 \), is 500 RMB.

BAC, the budget cost at the completion of the project, is the highest value of PV and the last point of PV cumulative curve. The simulated cost at completion is SCAC.

Exponential smoothing models include simple exponential smoothing (SES) and linear exponential smoothing (LSE). Khamooshi and Abdi (2016) have demonstrated that the combination of simple exponential smoothing model and earned duration indicator is more effective and justified than linear smoothing model, and the simple exponential smoothing model is easy to operate. Therefore, this paper will use the combination of CPI in EVM and simple exponential smoothing (SES) methods to predict the cost of the project at completion.

Exponential smoothing proposed by Brown is a common method used in project for forecasting. He stated that time series have stability or regularity, so it can be reasonably postponed and the recent past process has a greater impact on the future process to some extent, that is, more weight numbers are placed on the recent data.

The exponential smoothing method is neither a simple average method for whole period, that is, gives the same weight to all the data of time series, nor a moving average method, which does not consider the more long-term data and gives greater weight to the recent data. Instead, it does not give up the past data, but also gives the influence degree to historical data gradually weaken. With the distance of the data, it gives the weight to gradually converge to zero. There are many different but equivalent algebraic forms of simple exponential smoothing formula, most of which adopt the form of Brown [7]. Its principle is that the exponential smoothing value of any period is the weighted average of the actual observation value of the current period and the exponential smoothing value of the previous period. The simple exponential smoothing equation can be given as follows:
\[
S_t = \alpha \cdot y_t + (1 - \alpha) \cdot S_{t-1}
\]
(1)

where \( S_t \) represents the smooth value at time \( t \) (the predicted value at \( t+1 \)); \( y_t \) is the real value we concerned at time \( t \); \( S_{t-1} \) represents the smooth value at time \( t-1 \) (the predicted value at \( t \)); \( \alpha \) is the smoothing constant, and its value range is \([0,1]\).

The linear exponential smoothing formula is usually written in the following form:
\[
S'_t = \alpha \cdot S_t + (1 - \alpha) \cdot S'_{t-1}
\]
(2)

the above equation (2) shows that the simple exponential smoothing technique is applied again in equation (1). So the final M period forecast can be written as:
\[
S_{t+M} = a_t + M b_t
\]
(3)

where \( a_t \) is the level estimation at period \( t \),
\[
a_t = 2S_t - S'_t
\]
in which \( b_t \) is the trend estimation at period \( t \),
\[
b_t = \frac{\alpha}{(1-\alpha)}(S_t - S'_t)
\]

Let CPI\((t)\) be the project performance index based on EVM method, CPI\(^\prime\)(\(t\)) is to apply simple exponential smoothing to the performance index of 32 simulation activity network project data. According to the simple exponential smoothing model, CPI\(^\prime\)(\(t\)) can be obtained by the following:
\[
CPI'(t) = \alpha CPI(t) + (1 - \alpha) CPI'(t - 1)
\]
(4)

As a result, the final estimated cost at completion (ECAC) can be calculated by the combination of simple exponential smoothing technique and EVM method as:
\[
ECAC = AC + (BAC - EV)/CPI'(t)
\]
(5)
3. Real-life example
The simple exponential smoothing prediction equation described in the section 2 is applied to a 32 simulation activity network project. The data belongs to the actual capital equipment project of an industrial plant in South America, which is an EPC (Engineering-Procurement-Construction) project. It has the characteristics of highly dependent activities, scattered work, complex structure of various activities and uncertainty of accurate prediction of expected results (Yeo and Ning 2002; Yeo and Ning 2006) [8] [9]. There is a kind of network structure between the activities of such projects. At a certain point in time, one or more activities may be carried out at the same time, and the activities at the same stage may be affected by different activities.

The in-control duration of each activity $i$ of the project is subject to a triangular distribution, that is $d_{i0} \sim Tri(a_{i0}, b_{i0}, c_{i0})$ the parameters $a_{i0}$, $b_{i0}$, and $c_{i0}$ represent the minimum (Min), maximum (Max) and most likely (ML) in-control durations respectively, to describe the duration change of each activity. Activities 1, 9, 19 and 36 in the data are dummy activities without duration and cost. They are only used to organize the baseline schedule, so they are all taken as 0 in the operation process. Except for the activities 10, 11, 12, 13 and 14, the cost of other activities has a linear relationship with the project duration, and the cost of activities 10, 11, 12, 13 and 14 follow a uniform distribution, where $\beta_{i0}$ is the coefficient of cost with respect to the project duration. Due to the confidentiality policy of the project, the data in this paper have been adjusted, but without losing accuracy (Votto et al. 2020) [10].

Applying exponential smoothing technique (with $\alpha=2$), the cost of each time period of the project can be observed in Figure 2:

The cost of tens of thousands of simulations and the cost predicted by the combination of CPI from EVM and exponential smoothing technology are almost the same, especially in the later stage of the project.

![Figure 2. Cost estimates of simulations and forecasts](image)

In order to illustrate the performance of the forecast results, the root mean square error of the forecast results is divided by the final project budget cost to obtain the ratio

$$R = \left(\frac{1}{n} \sum_{k=1}^{n} (Y_k - P_k)^2 \right)^{1/2} / SCAC$$  \hspace{1cm} (6)

where $Y_k$ is the predicted value of the actual value $P_k$, $n$ is the number of project period or events (Faria et al.2009) [11], $SCAC$ is the simulated cost at completion. For tens of thousands of simulations, the
ratio R value is 0.02157419, which shows that for the final total cost of the project, the difference between the predicted result and the actual value is very small, indicating that the combination of exponential smoothing technology with CPI from EVM is very reasonable for the final cost estimation of the project.

4. Conclusion
Performance indicators from EVM provide managers and project teams with the necessary data to track the actual performance of activities, which can be used to describe the impact and performance of the current project more clearly and intuitively with the leadership. With the gradual maturity of EVM, it can successfully and effectively help the project manager to find and solve problems as soon as possible in the project reporting period. The prediction of the project makes the follow-up project within the control of the project manager as much as possible, so that the final cost and duration are in an ideal range.

This paper evaluates the combination of CPI from EVM and simple exponential smoothing (SES) technology to predict the final estimated cost of the project. The research results support this idea very well. Cost performance indicators play a key role in the prediction of project cost. Simple exponential smoothing technology (SES) is easy to use and formulate, which makes the final cost prediction of the project easy to operate and the programming easier to understand. In this paper, only one kind of project has been studied, and the research on other projects needs to be continued.

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