Stochastic method for forecasting project time and cost

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ABSTRACT
This paper presents a new method for forecasting time and cost of construction projects at completion and/or at any intermediate time horizon. The method is designed to overcome limitations of current applications of earned value method in forecasting project cost and durations. The method adopts recently introduced extensions to EVM and the project ratios technique for progress reporting. It introduces modifications and developments that allow more accurate and practical results. Unlike the current applications of EVM method, the proposed method uses simulation to generate stochastic S-curves based on past performance achieved by contractors. The method enables the user to assess the uncertainty associated with forecasted project cost and duration at completion so that appropriate corrective actions can be taken, when needed. A numerical example is presented to demonstrate the use of the proposed method and to illustrate its improved forecasting accuracy over current methods. The results obtained by the developed method demonstrate the effectiveness of (1) using project ratios technique in forecasting project time and cost comparing to that obtained by traditional EVM method; (2) measuring the status of critical activities only, is particularly useful in forecasting project durations; and (3) accounting for uncertainties involved in the forecasting process provides flexibility in modelling forecasted project time and cost.

Category: Construction Planning, EVM, tracking and control, and forecasting with uncertainty

INTRODUCTION
Forecasting project performance is a critical management function in tracking and controlling execution of construction projects. The literature reveals that many models and methods have been developed since the introduction of EVM in the mid-1960s (e.g., Eldin and Hughes 1992; Alshibani, 1999; Moselhi et al 2004; Gabriel et
al 2004; Moselhi and Hassani, 2003; Nasira and Abd.Majid, 2006; Vandevenoorde and Vanhoucke 2006; Kim 2007; Kim and Reinschmidt 2011; Moselhi 2011, Moselhi and Xiao 2011). Zwikael et al (2000) conducted a study to measure the performance of different models developed in forecasting project cost. The models were drawn from the literature and they were based on one of the following five assumptions: (1) cost variances at report date will be corrected by the time the project is completed, and the cost at completion will be equal to the planned cost; (2) the cost of the remaining work of the project will be executed according to the original plan, and the cost variances at reporting date will not change at project completion; (3) the cost performance index (CPI) achieved up to reporting date will remain through the remaining work (Shtub et. al., 1994); (4) the cost performance index and the schedule performance index will affect the project final cost; and (5) the remaining work will be performed as a function of both the cost performance index and the schedule performance index. The authors used a sample of actual projects and they concluded that the worst model in forecasting project cost is the one that is based on the assumption that the future performance will recover and the project will complete within the original budget, while the models that incorporate both the SPI and the CPI were inferior to the two models based on the CPI only. In addition, the models that are based on the assumption that the achieved CPI will continue for the remaining work gives the best most accurate forecasts results.

Despite its wide acceptance and use, earned value based forecasting methods have received many criticism by researchers, especially in forecasting project duration (e.g. Vandevoorde and Vanhoucke 2006; Moselhi 2011). Most criticism focuses on three fundamental aspects: (1) schedule performance of a project is measured, analyzed, and predicted in units of value (e.g., money, labour, work quantity, and percent complete) instead of time unit (Kim and Reinschmidt 2011); (2) using schedule performance index (SPI) or schedule variance (SV)to forecast project duration can be misleading (Vandevoorde and Vanhoucke, 2006; Moselhi 2011); and (3)earned value method is a deterministic and provide point forecasts that does not provide information on the prediction bounds based on the likely accuracy of forecasts (Kim and Reinschmidt 2011).

In an effort to overcome some limitations of using earned value for forecasting project performance, several models were developed (Vandevoorde and Vanhoucke, 2006; Moselhi, 2011). Vandevoorde and Vanhoucke (2006) compared three different methods to forecast project duration using earned value metrics and evaluate them on real-life project data. The authors concluded that the three methods produce a similar forecasting accuracy in the linear planned value case. However, introducing learning curves for the three methods may provide much more realistic forecasting accuracy. Moselhi 2011 introduces a novel concept for the schedule performance index that measures the status of critical activities only and uses this index to forecast project duration.

This paper presents a newly developed method for forecasting project cost and time in an effort to circumvent the above stated limitations of current methods.
The method adopts recently introduced extensions to EVM by Moselhi 2011 and the project ratios technique developed earlier by Eldin and Hughes (1992) and introduces modifications that allow for providing information on the prediction bounds based on the likely accuracy of the forecasts.

**PROPOSED METHOD**

The proposed method utilizes recent extensions to EVM by Moselhi (2011) and the project ratios technique introduced by Eldin and Hughes (1992) for forecasting project cost and time. The method models the uncertainty associated with the forecasting process using Monte Carlo simulation. The schedule performance index (SPI) and cost performance index (CPI) are calculated first. Unlike currently used methods, these indices are calculated at the activity level by comparing actual performance to that as planned. The user is then required to define the uncertainties associated with \((\text{Whr}/Q)a\) and \(($/Q)a\) for remaining work. Risk analysis is performed to model the uncertainty associated with the forecasting process. Clearly the cumulative nature of uncertainty increases with time away from the actual conditions captured at the reporting date as shown in Figure 1.

![Figure 1. Proposed method](image-url)
1. **Schedule Performance Index (SPI)**
   This index provides a measure of the likelihood of finishing planned work within its targeted duration and it is used here to forecast project duration. The index can be expressed as:
   \[
   \text{SPI} = \frac{(\text{Whr} / \text{Q})_b}{(\text{Whr} / \text{Q})_a}
   \]  
   (1)
   
   In which:
   
   
   (Whr / Q)_a is the actual to-date working hours per unit of work;
   
   (Whr / Q)_b is the budgeted working hours per unit of work.

2. **Cost Performance Index (CPI)**
   The cost performance index (CPI) provides a good measure as to how close an activity and hence a project will be completed within its targeted budget and it is used here to forecast project cost. The CPI can be expressed as:
   \[
   \text{CPI} = \frac{(\$/\text{Q})_b}{(\$/\text{Q})_a}
   \]  
   (2)
   
   In which:
   
   
   ($ / \text{Q})_b is the budgeted cost of unit rate;
   
   ($ / \text{Q})_a is the actual cost to date of unit rate.

3. **Forecasted Cost and Time Targeted Time Horizon (t_i):**

3.1 **Cost forecast**
   The cost forecast is calculated assuming that the achieved performance at reporting date is to continue to project completion date and it is calculated at activity level.
   \[
   CF_{t_i} = \left( \text{ACWP} + (Q)_b - (Q)_a \right) \times (\$/\text{Q})
   \]  
   (3)
   
   In which:
   
   CF_{t_i} is the cost forecast @ t_i;
   
   ACWP is the actual cost of work performed at report date;
   
   (Q)_b is the budgeted quantities;
   
   (Q)_a is the actual quantities up to report date;
The user needs to define the maximum and minimum values of the selected distributions that best represent uncertainties associated with the unit cost ($/Q$) of the remaining work of individual activities; taking into consideration factors that may affect the performance in near future such as weather condition, material availability, work complexity, etc.

### 3.2 Time forecast

The time forecast is also calculated assuming that the achieved productivity performance at report date is to continue to the project completion and it is calculated at activity level of critical activities only.

\[
TF_{ti} = (\text{Whr})_{td} + ((Q)b - (Q)a) \times (\text{Whr} / Q)
\]

In which:

- $TF_{ti}$ is the time forecast at $t_i$;
- $(\text{Whr})_{td}$ is the number of working hours spent up to reporting date.

The proposed method enables the user to set a range associated with the calculated cost and schedule indices to stochastically forecast the project cost and duration. This results in forecasting a range rather than a single crisp value. This could prove useful to project managers to examine the forecasted values and along with values generated from different scenarios to better understand the impact of likely uncertainty. The user can select from different probability distributions to model the uncertainty over each specified range (e.g. Normal, Triangular, Beta, Uniform, etc.). Aside of the defined ranges, the user may also have to provide the most likely value for certain distributions. It is important here to note that this uncertainty modelling is performed on all project activities in forecasting project cost and only on critical activities in forecasting project duration (Moselhi 2011). Figure 2 depicts the probability distribution of the unit cost and working hours of the remaining work for activity A as defined by the user in performing the risk analysis.

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**Figure 2. Probability distribution of the actual unit cost and working hours**
4. Cost Variances

In addition to forecasting project cost and time, the proposed method calculates project cost and time variances at any targeted future date. The cost variance (CV) is determined by subtracting forecasted cost from that budgeted at that point in time. Similarly, the time variance (TV) is determined by subtracting forecasted time from that planned. The time variance is calculated in units of time.

\[ CV_{ti} = \% \text{ complete} \times (Q)b \times (S/Q)b \times CF_{ti} \]  
\[ TV_{ti} = \% \text{ complete} \times (Q)b \times (Whr)b \times TF_{ti} \]

In which:

- \( CV_{ti} \) is the cost variance at (ti) in horizon time;
- \( TV_{ti} \) is the time variance at (ti) in horizon time and measured in working hours;
- \( CF_{ti} \) is the cost forecast calculated using Equation (3);
- \( TF_{ti} \) is the time forecast calculated using Equation (4).

It is essential to note that in defining the uncertainties associated with the performance of the remaining work, the user can partially block out certain past time periods during which exceptional conditions are known to have prevailed and are likely not to occur in future periods such as strike. Instead of blocking out the entire period, the performance index for this period is calculated based on the level of performance achieved by the contractor during a period of normal conditions; just before the occurrence of such unusual conditions. For example if a strike occurred in the second period, instead of blocking out this period entirely, its performance index can be calculated at normal conditions just before the strike.

EXAMPLE PROJECT

To illustrate the features of the proposed method in forecasting project duration at completion and to highlight the limitations of current methods, an example project is described. The PDM network of this project is shown in Figure 3 and the project Gantt chart is presented in Figure 4. The project has duration of 8 month and the latest progress period is at half way of its planned original duration. The project data is shown in Table 1. Table 2 shows the actual progress data at the end of month 4. Figure 5 depicts the project progress at the end of month 4.
Figure 3. PDM network of example project

Figure 4. A Gantt chart for project example

Table 1. Activities Durations and Direct Cost

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration(hrs)</th>
<th>Total Direct $</th>
<th>Q</th>
<th>BCWS</th>
<th>($/Q)p</th>
<th>(Whr/Q)p</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>176</td>
<td>1000</td>
<td>100</td>
<td>1000</td>
<td>10.00</td>
<td>1.76</td>
</tr>
<tr>
<td>B</td>
<td>528</td>
<td>12000</td>
<td>400</td>
<td>1200</td>
<td>30.00</td>
<td>1.32</td>
</tr>
<tr>
<td>C</td>
<td>176</td>
<td>4000</td>
<td>150</td>
<td>4000</td>
<td>26.67</td>
<td>1.17</td>
</tr>
<tr>
<td>D</td>
<td>1056</td>
<td>6000</td>
<td>600</td>
<td>8000</td>
<td>10.00</td>
<td>1.76</td>
</tr>
<tr>
<td>E</td>
<td>352</td>
<td>16000</td>
<td>220</td>
<td>8000</td>
<td>72.73</td>
<td>1.60</td>
</tr>
<tr>
<td>F</td>
<td>176</td>
<td>1000</td>
<td>180</td>
<td>0</td>
<td>5.56</td>
<td>0.98</td>
</tr>
</tbody>
</table>

P: planned
Table 2. Actual Progress at activity level at the end of the month 4

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration</th>
<th>% Complete</th>
<th>ACWP</th>
<th>($/Q)\text{a}</th>
<th>(Whr/Q)\text{a}</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>180</td>
<td>100</td>
<td>1100</td>
<td>11.00</td>
<td>1.80</td>
</tr>
<tr>
<td>B</td>
<td>520</td>
<td>100</td>
<td>11000</td>
<td>27.50</td>
<td>1.30</td>
</tr>
<tr>
<td>C</td>
<td>170</td>
<td>100</td>
<td>3500</td>
<td>23.33</td>
<td>1.14</td>
</tr>
<tr>
<td>D</td>
<td>528</td>
<td>30</td>
<td>6500</td>
<td>36.11</td>
<td>2.93</td>
</tr>
<tr>
<td>E</td>
<td>352</td>
<td>35</td>
<td>8000</td>
<td>103.90</td>
<td>2.29</td>
</tr>
<tr>
<td>F</td>
<td>176</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

\text{a: actual progress}

![Graph showing As planned vs actual cost](image)

Figure 5. Progress curves of the example projects at the end of month 4

**Outputs**

The proposed methodology was performed using Equations 1 to 6. The analysis was carried to determine project cost and schedule status at the end of month 4 and to forecast the project cost and duration at completion. A triangle distribution was selected, for simplicity; to define the uncertainties associated with the project cost and time variables ($/Q), (Whr/Q)\text{). Figure 2 depicts the probability distributions used to define the actual unit cost and working hours of the example project. Table 3 presents the outputs of the developed method in forecasting project cost and time at completion. Figure 4 depicts screen printout of the risk analysis system software of the forecasted project cost and time at completion.
Table 3. Developed method outputs

<table>
<thead>
<tr>
<th>Forecast Name</th>
<th>CAC</th>
<th>TAC</th>
<th>Cost variances</th>
<th>Time variances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>60,153.00</td>
<td>9.55</td>
<td>-20153.00</td>
<td>-1.55</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>842.68</td>
<td>0.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td>57,850.28</td>
<td>9.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>62,418.77</td>
<td>9.89</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variance</td>
<td>710,116.36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td>59,034.73</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>90%</td>
<td>61,245.56</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4. Cost and time forecast at project completion

SUMMARY AND CONCLUDING REMARKS
A new method for forecasting project time and cost at completion and/or at intermediate targeted dates is presented. The proposed method utilizes recent extensions to EVM and project ratios technique to circumvent limitations in current methods. The developed method enables contractors to evaluate risk that may rise for different scenarios in the forecasting process and accordingly generates reliable forecasts. The method is also flexible; allowing for the exclusion of incidents and events that are likely not to occur on future reporting periods (such as strikes and extreme weather conditions). The proposed method is more suitable when a historical data of similar project is available and when the duration of the project is relatively long to establish distributions of the activities and remaining work of the activities.

The basic components of the developed method are described, and an example project was analyzed to illustrate the features of the developed method in forecasting project cost and time.
REFERENCES


