Iranian Journal of Management Studies (IJMS) *http://ijms.ut.ac.ir/*
Vol. 9, No. 1, Junuary 2016 *Print ISSN: 2008-7055*
pp. *63-75* *Online ISSN: 2345-3745*

An extension of the earned value management to improve the accuracy of schedule analysis results

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(Received: 19 November, 2014; Revised: 10 March, 2015; Accepted: 19 March, 2015)

Abstract

A project is any endeavor involving planned action, for example, developing a new product or constructing a dam. Major factors for a project to be successful are applying performance measurement and feedback tool. One such well-known performance measurement tool to control the project execution is earned value management (EVM). EVM uses the fundamental principle that trends in the past can be good predictors of the future. It was originally developed to follow time and cost of a project, but it has some weak points in analyzing the time performance of a project. In this article, we first explain these weak points in detail. Then, to improve them, we develop two methods: the first one is a simple and approximation method to minimize errors in EVM analysis with a high probability and the second method is an exact approach that uses earned value and floating time concepts. At the end, the performance of the proposed methods is evaluated and analyzed on a set of instances containing a variety of project sizes. The results of this experimentation show that the efficiency of the methods is relatively good.

Keywords

Earned value, Project delay, Project management, Schedule analysis.

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Introduction

One of the most effective performance measurement and feedback tools for managing a project is earned value management (EVM). It provides a means to forecast future performance of the project based upon its past performance by utilizing a fundamental principle that patterns and trends in the past can be good predictors of the future. EVM allows the calculation of cost and schedule variances and the forecast of a project's cost and schedule duration (for an overview see Anbari, 2003). Although EVM was set-up to follow time and cost, the majority of the research have focused on the cost aspect alone. Nevertheless, EVM provides two well-known schedule performance indices: the schedule variance and the schedule performance. These two measures are useful indicators to analyze a project's performance; however, they have some problems. For example, they are based on monetary unit and not on time. They can behave in ways that are not normally expected of schedule indicators and predictors. Furthermore, it is also possible that an earned value analysis may show that the project is delayed; on the contrary, the project would be on time. In this study, we consider these aforementioned problems and propose two new methods to resolve them.

EVM was introduced by agencies of the U.S. federal government as a part of the control system criteria. Nowadays, it is believed that EVM has many advantages and would control the performance of a project, but there are a few studies on EVM. Lipke (1999) developed cost and schedule ratios to manage cost and schedule reserves in projects. Lipke (2003) also introduced the earned schedule. Henderson (2003, 2004) studied the applicability and reliability of the earned schedule. Anbari (2003) enhanced the effectiveness of earned value implementation. Kim *et al*. (2003) studied the implementation of earned value in different types of organizations and projects. Lipke (2004) developed project cost and time performance probabilities. In addition, Vandevoorde and Vanhoucke (2005) concluded that the best and the most reliable method to estimate time at completion is the earned schedule method. A new notation for the earned value analysis is presented in Cioffi (2006) to make EVM mathematics more transparent and flexible. Lipke *et al*. (2009) provided a reliable forecasting method of the final cost and duration to improve the capability of project managers for making informed decisions. Moslemi-Naeni *et al*. (2011) presented a new fuzzy-based earned value model with the advantage of developing and analyzing the earned value indices and the time and the cost estimates at completion under uncertainty. Pajares and López-Paredes (2011) introduced two new metrics for integrating EVM and project risk management methodologies: cost control and schedule control indices. These two indices compare EVM measures with the maximum value that a project should exhibit if the project was running under the risk analysis hypothesis. Moslemi-Naeni and Salehipour (2011) developed new indices under fuzzy circumstances and evaluated them using alpha cut method. Acebes *et al*. (2013) proposed a graphical framework for EVM to integrate the dimensions of project cost and schedule with risk management. Hunter *et al*. (2014) focused on the implementation of EVM on the Radiation Belt Storm Probes project to improve cost monitoring and control. Czemplik (2014) applied EVM to progress control of construction projects. Recently, some more studies have been published regarding other aspects of EVM (Acbes *et al*., 2015; Colin *et al*., 2015; Kim *et al*., 2015).

Table 1 summarizes the most important works in the literature.

Table 1. Summary of the literature review

Authors	Year	Approach	Error at schedule analysis	Other consideration
Lipke	1999	Heuristic	Yes	
Lipke	2003	Heuristic	Yes	Introduced earned schedule
Henderson	2003	Heuristic	Yes	Applied earned schedule
Anbari	2003	Heuristic	Yes	
Kim *et al*.	2003	Heuristic	Yes	Implemented EVM
Henderson	2004	Heuristic	Yes	Applied earned schedule
Lipke	2004	Heuristic	Yes	
Vandevoorde and Vanhoucke	2005	Heuristic	Yes	
Cioffi	2006	Heuristic	Yes	
Lipke *et al*.	2009	Heuristic	Yes	

Continue Table 1. Summary of the literature review

Authors	Year	Approach	Error at schedule analysis	Other consideration
Moslemi-Naeni *et al*.	2011	Heuristic	Yes	Fuzzy data
Pajares and López-Paredes	2011	Heuristic	Yes	Integrated EVM and project risk management
Moslemi-Naeni and Salehipour	2011	Heuristic	Yes	Fuzzy data
Acebes *et al*.	2013	Heuristic	Yes	A graphical framework
Hunter *et al*.	2014	Heuristic	Yes	
Czemplik	2014	Heuristic	Yes	Application of EVM
This research		Exact	No	Propose two new methods

As shown in Table 1, heuristic method was the most common approach in all the aforementioned studies; therefore, it was difficult to ensure whether the project was ahead or behind the schedule and its cost. Hence, in this article, we consider this problem and propose two methods for improving the accuracy of schedule analysis results.

Earned Value Management: Basic Concepts

EVM integrates a project’s scope, schedule, and cost into a unified set of prescribed metrics to monitor and forecast the project’s performance. Building blocks of all EVM metrics are the following three elements (Kerzner, 2013):

- Earned value (EV) or budgeted cost of work performed (BCWP): it is the budgeted amount for the work actually completed on the schedule activity or work breakdown structure (WBS) component during a given time period.
- Planned value (PV) or budgeted cost of work scheduled (BCWS): it is the budgeted cost for the work scheduled to be completed on an activity or WBS component up to a given point in time.
- Actual cost (AC) or actual cost of work performed (ACWP): it is the total cost incurred in accomplishing work on the schedule activity or WBS component during a given time period.

These data points can be used to analyze the current status of a project and forecast its likely future. EVM analysis has two parts: cost analysis and schedule analysis. In schedule analysis, EVM uses both schedule variance (SV= EV−PV) and schedule performance index (SPI= EV/PV). Also, cost variance (CV= AC−PV) and cost performance index (SPI= AC/PV) are used in cost analysis of the EVM.

Whenever CV<0 and CPI<1, the project is over budgeted (otherwise, if CV>0 and CPI>1 the project is under budgeted). Furthermore, if SV<0 and SPI<1, the project is delayed (otherwise, if SV>0 and SPI>1 the project is ahead of schedule). When CV= 0 (CPI= 1) and/or SV= 0 (SPI= 1) the project is respectively on cost and/or timely.

Whenever SV<0 and SPI<1, the project is delayed (otherwise, if SV>0 and SPI>1 the project is ahead of schedule). If CV<0 and CPI<1, the project is over budgeted (otherwise, if CV>0 and CPI>1 the project is under budgeted). When CV= 0 (CPI= 1) and/or SV= 0 (SPI= 1) the project is respectively on cost and/or timely.

By means of monitoring the evolution of these indices over the project's life cycle, managers can detect deviations from plan so that they can take early corrective actions.

Problem Description

The SV and SPI measures are useful indicators and predictors of project's performance. However, SV does not measure time and is expressed in a monetary unit. In EVM, using SPI and the average planned value per unit time, the project manager can generate a rough estimate of when the project will be completed, if current trends continue, compared to when it was originally supposed to be completed. Obviously, this method generates a fairly rough estimate and must always be compared with the status reflected using a time-based schedule method, such as CPM. It is possible that an earned value analysis could show no schedule variance and yet the project is still behind schedule; for example, when tasks that are planned to be completed in the future are performed ahead of tasks on the critical path. For example, consider a project network with seven activities. Figure 1 shows the activity-on-arrow representation of the network.

Table 2 presents the durations and the budgeted requirements of the activities.

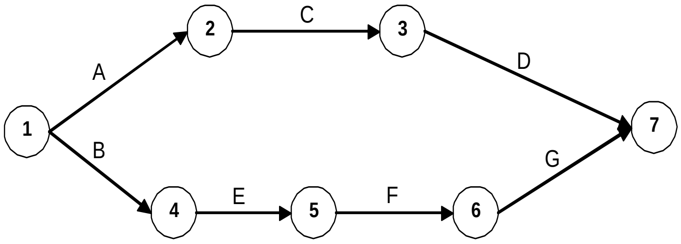

Fig. 1. The project network of the example problem

Table 2. Activity data of the example problem

Activity	Duration	Budgeted
A	2	10
B	1	20
C	4	10
D	4	10
E	3	30
F	2	30
G	1	20

Figure 2 represents the schedule plan of the project. A, C, and D are the critical activities

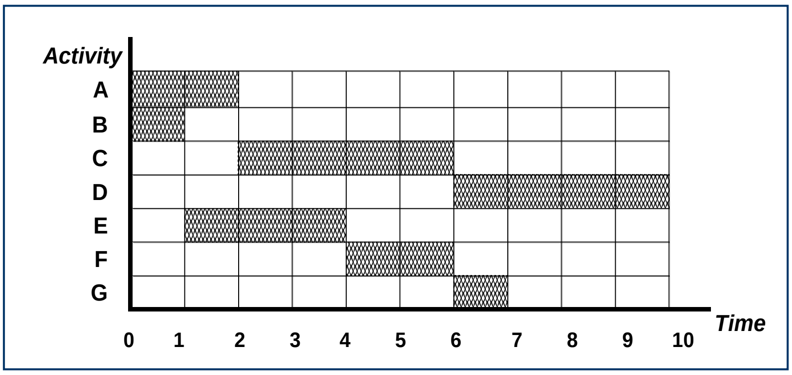

Fig. 2. The plan of the example project

After lasting 3 time units, a performance report is received as shown in Table 3.

Table 3. The Performance Report of the Example Problem

Activity	Percent Complete	Actual tart	Actual Finish
A	100	0	2
B	100	0	1
E	100	1	3
Other activities	0	-	-

If we assume that activity effort is distributed uniformly among its duration, we can obtain EV= 60 and PV= 52.5 and according to EVM formula, schedule variance and schedule performance indices are determined as +7.5 and +1.14, respectively. In other words, SPI states the project is 14% ahead of the plan. But, if a time-based scheduling method is applied, such as CPM, we obtain that there is one time unit delay with the project. Hence, SPI and SV are not good criteria for schedule analysis in all cases. This problem occurs because SPI and SV ignore critical path and precedence relations between activities.

Two Methods for Schedule Analysis

In this section, based on the EVM concepts, we propose two methods to solve the aforementioned problem.

A simple and approximation method

A simple method is to calculate and analyze SPI or SV of critical path beside SPI or SV of total project. To summarize, Table 4 shows "at-a-glance" what this method indicates about schedule analysis.

Table 4. Interpretations of performance measures

Performance Measures		SV and SPI at project level		
		>0 and >1.0	**=0 and=1.0**	**<0 and <1.0**
SV and SPI for critical path	>0 & >1.0	* Ahead of project schedule	* Ahead of project schedule * But for non-critical activities behind of their schedule	* Ahead of schedule for critical activities * But for non-critical activities too behind of their schedule * For schedule analysis time-based schedule method must be used
	=0 and =1.0	* On schedule * But for non-critical activities ahead of their schedule	* On schedule	* On schedule for critical activities * But for non-critical activities too behind of their schedule * For schedule analysis, time-based schedule method must be used
	<0 and <1.0	* Behind schedule * But for non-critical activities ahead of their schedule	* Behind schedule * But for non-critical activities ahead of their schedule	* Behind schedule

SPI: cost performance index; SV: schedule variance.

For instance, consider the example project of section two. The SPI of critical path is equal to 0.80 and then the project is behind of schedule. Therefore, the SPI of total project cannot apply singly for schedule variance.

This method can help in minimizing errors in EVM schedule variance, but still there is some probability of error occurrence here. As an example, consider a case where CPI of total project and CPI of critical path both state that work is ahead of project, but a near critical path at project is behind schedule which created project delay. Of course, probability of this case is very low. Hence, we develop another method for exact schedule analysis proposed in the next section.

An exact method

In this section, a new method is presented for exact schedule analysis and calculation of duration of schedule variance with zero probability of error. The method applies EV, PV, and floating time concept for schedule analysis. Solution of this method is equaled to the status reflected by a time-based schedule method, such as CPM. To do this, we first state some required definitions.

Definition 1

Plan floating time of an activity in a plan is equal to the difference between the activity's starting time in the plan and its earliest starting time obtained by the critical path method.

Definition 2

An activity is hermaphrodite if both of EV and PV of the activity be equaled to zero.

Now, we are ready to describe the executive steps of the proposed algorithm as follows:

Step 1. Cut the project network from nodes so that all hermaphrodite activities are placed on one side.

Step 2. Identify activities that terminate cutting nodes.

Step 3. Calculate active floating times (AFT) of the identification activities that is calculated as follows:

If EV= 0 then AFT= PFT − (DT − PS)

If EV>0 then AFT= PFT − ((AS − PS) + (DT − AS)(EV/B) − D) where, DT is data time or time of data gathering, AS is actual starting time of activity, PS is planned starting time of activity, B is the activity budgeted, and D is the activity duration.

Step 4. Minimum AFT of all activities (AFT_{min}) states that exact amount of schedule variance in scale of time unit.

If $AFT_{min} = 0$ then the project is on schedule, and there is no delay.

If $AFT_{min} > 0$ then the project is ahead of schedule for AFT_{min} time units.

If $AFT_{min} < 0$ then the project is behind schedule for AFT_{min} time units.

A numerical example

For instance, consider the example project shown in Figure 1. We cut the project network as shown in Figure 3.

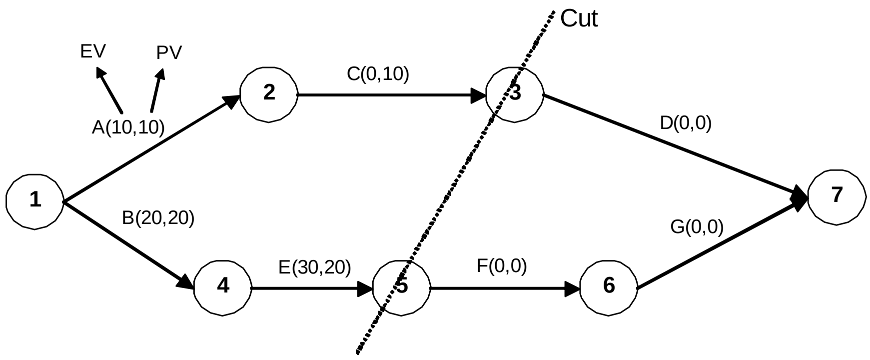

Fig. 3. The Cut of the Project Network

Nodes 3 and 5 are cutting nodes. Therefore, we calculate active floating times of C and E as shown in Table 5.

Because $AFT_{min=}$ −1, according to the procedure, the project is behind schedule by one unit time. This result is equaled to result of the time-based schedule method, such as CPM.

Table 5. Calculation of Active Floating Time at the Example

Activity	EV	AFT formula	AFT	AFT_{min}
C	0	AFT= PFT − (DT − PS)	−1	−1
E	30	AFT= PFT − (AS − PS) + (DT − AS)(EV/B) − D)	4	

Computational results

In this section, we present the performance of the proposed methods introduced in the previous section. To do this, first three collections of problems with 10, 20, and activities are considered for the experiments. Then, to evaluate the performance of the methods, we solved the test problems by a time-based schedule method. Table 6 contains a summary of the computational results.

Table 6. The computational results

No. of activities	No. of test problems	A	B	C	D
10	10	10	10	100%	100%
20	10	10	10	100%	100%
30	10	9	10	90%	100%
Total	30	29	30	96.6%	100%

We define the columns of Table 6 as follows:

A) Number of problems in which the first method was obtained the right solutions

B) Number of problems in which the exact method was obtained the right solutions.

C) Percentage of problems in which the first method was obtained the right solutions

D) Percentage of problems in which the exact method was obtained the right solutions.

The results of Table 6 show that in 96.6% of the test problems, the first method obtained the right solutions; however, the exact proposed method obtained the right solutions in all of the test problems. Therefore, the results of the experimentation are quite satisfactory.

Conclusions

In this article, we stated one of the EVM's problems about schedule analysis. To solve the problem, we proposed two methods. One of the methods is a simple approximation method. It proposed that SPI or SV of critical path(s) should be analyzed beside analysis of SPI or SV for total project. This method can help to minimize errors in EVM schedule variance. Results of the second method are exact. In this method, schedule analysis is done using EV and floating time exactly, and its result is equaled to the status reflected by a time-based schedule method. Some extensions of this research might be of interest. While in this article, we only considered the “finish-to-start precedence model” some other precedence models such as generalized precedence relations might be considered in the project. The other extension of this research would be to investigate the problem in fuzzy environment.

Acknowledgement

This study was supported by a grant from the Islamic Azad University, Qazvin Branch, so the authors gratefully acknowledge this support.

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