Available online at www.sciencedirect.com

ScienceDirect

International Journal of Project Management 29 (2011) 1082 – 1090

International Journal of Project Management

www.elsevier.com/locate/ijproman

A time-dependent earned value model for software projects

Roger D.H. Warburton *

Metropolitan College, Boston University Boston, MA 02215, USA

Received 23 August 2010; received in revised form 16 February 2011; accepted 17 February 2011

Abstract

This paper proposes a formal method for including time dependence into Earned Value (EV) management. The model requires three parameters, which map directly to the fundamental "triple constraint" of scope, cost, and schedule: the reject rate of activities, the cost overrun parameter, and the time to repair the rejected activities. Time dependent expressions for the planned value, earned value, and actual cost are derived, along with the cost performance index (CPI) and schedule performance index (SPI). The model is built on the well-established Putnam–Norden–Rayleigh (PNR) labor rate profile, which is a useful representation for large software projects. We apply the model to a well-known software dataset, demonstrating how to estimate the project's final cost, which converges faster to the correct answer with less variability than standard Estimate-at-Completion (EAC) calculations. The model also accurately predicts the required revised labor profile and the new schedule.

Keywords: Earned Value Management; Cost estimation; CPI; SPI

1. Introduction

The Practice Standard for Earned Value Management (EVM) (Project Management Institute, 2005a) provides insight into and explanation of the basic elements of EVM. Marshall (2006) suggests that EVM is effective in providing significant predictors of project status. EVM metrics were also shown to be important contributors to the successful administration of contracts (Marshall et al., 2008).

On the other hand, Kim (2000) found that few projects were using EVM, and the main reasons were that it was "not needed on small projects" and it was "hard to apply." Kim also pointed out that computer tools and training significantly improved the acceptance and performance of EVM, and that the literature suffers from an "over reliance on anecdotal data."

The key concept is the Earned Value (EV), which converts project accomplishments from physical units of measure (e.g., miles of roadway or deliverables completed) to financial units (e.g., dollars or labor hours). The general method was established by Cioffi (2006a), who showed how to convert, for example, attorney minutes or bulldozer days into the common unit of dollars.

EVM provides project managers with triggers or early warning signals of project trouble, which were found to be reliable as early as 15% into a project (Christensen and Heise, 1992). Data from completed Air Force contracts established that the cost performance index (CPI) did not change by more than 10% once the contract had reached the 20% completion point, regardless of the type or phase of the defense contract, weapon system, or the military service involved (Christensen and Payne, 1991).

Therefore, a significant overrun which continues more than 20% into the project indicates that the project is unlikely to meet the budgetary goals, and customers can reliably conclude the project is in trouble. Christensen et al. (1995) clearly established that performance measurement data (such as the CPI) have predictive value. Christensen and Payne (1991) added that if anything, the CPI tended to decline, and so using the CPI actually provides a lower bound for the final cost estimate.

Somewhat overlooked is what we will refer to as "instantaneous" values for the CPI. For example, less than

* Tel.: +1 617 358 3583; fax: +1 617 353 6840.
E-mail address: rwarb@bu.edu.

0263-7863/$ - see front matter
doi:10.1016/j.ijproman.2011.02.008

10% of contracts have 3-month stable CPI values. That means almost all measured values of the CPI, continually recomputed over short, 3-month intervals, were found to change (were unstable). Less than one third of projects have stable 6-month CPIs. Christensen (1992) established that despite the variability, the continually updated 3-month averages provided the most reliable estimate of the final cost.

These ideas suggest that the instantaneous CPI changes overtime, and as Christensen and Payne (1991) observed, only stabilizes because of its cumulative nature. Here we should carefully distinguish two types of variation in the CPI: 1) Statistical fluctuations in the data, i.e., the inherent uncertainty and variation in project data. 2) The existence of a functional time dependence. It is this latter variation, which is rarely discussed, that we will analyze in this paper.

A functional time dependence is important because the CPI is used to compute the estimate at completion, EAC, and a changing CPI implies a changing EAC. We suggest, however, that if the EAC is to be a useful concept, it should not change overtime. Customers want to know the final budget, and might be understandably upset at a continually changing estimate of the final project cost. We will demonstrate that there are several reasonable time-dependent shapes for the CPI, but that the resulting EAC is in fact a constant.

In general, methods for calculating the EAC depend on the assumptions made about the future performance of the project versus the historical, established performance to date. The Project Management Institute (2004) provides three approaches, based on three different sets of assumptions: (1) when the original estimates are flawed; (2) when past performance is not a good predictor of future performance; and, (3) when past performance is a good predictor of future performance.

There are a number of issues in the theory of EVM. For example, as pointed out by Cioffi (2006a), the schedule variance, SV, is not really a variance, which has statistical implications, but is really a schedule "difference." Further, SV is in dollars (not weeks or months), strange units for a schedule quantity. Cioffi (2006b) also proposed a revised formalism for EVM in an attempt to address the problem that "the historically arcane terminology and calculational notation have stood as road blocks to its embrace by the management community."

Another criticism of EVM is that schedule performance index, SPI, is inherently a function of time, but the form of the time dependence is unknown. This can be most easily be seen by examining the behavior of SPI towards the end of the project. As the last few activities are completed, the earned value approaches the planned value, i.e., $EV \rightarrow PV$, and therefore, $SPI \rightarrow EV/PV \rightarrow 1$ (Kerzner, 2006; Lipke, 2003). This is true even if the project is late, in which case the $SPI \rightarrow 1$ after the planned completion date. A reasonable question, therefore, is: How and when does $SPI \rightarrow 1$.

A goal of this paper is to improve the theory of EVM by including time dependence into the definitions of all quantities. By knowing the time dependence of CPI and SPI, and measuring the mat defined points in time, we show that it is possible to estimate precisely the project's final cost and schedule. In the literature, this issue has been addressed in two ways:

1. Method #1: Converting SV into time units (Anbari, 2003). One first calculates an average of the actual costs spent per time-period, called the spend rate (*AC Rate*), and the average planned value per time-period, called the planned value rate, (*PV Rate*). *PV Rate* is defined as the baseline budget at completion (*BAC*) divided by the baseline schedule at completion (*SAC*), which converts *SV* into time units, and is referred to as the time variance (*TV*).
   There are problems with this method: e.g., *PV Rate* is assumed constant over the life of the project, and yet the labor profile typically follows an 'S' curve.
2. Method #2: Measuring the time delay between the earned value and the planned value cost curves (Fleming and Koppelman, 2005). This is referred to as the Schedule Variance Method, SVM. A quantity called the "Earned Schedule" is determined by drawing a horizontal line from the EV curve backward (or forward) to the PV curve, and interpreting the distance on the horizontal time axis as a measure of the schedule delay (or acceleration). This method has the advantage of defining the schedule delay in time units. However, there are problems with this method also. The dimensionless ratio in the formula for *ES* presents an algebraic difficulty as pointed out by Book (2006).

Vanhoucke and Vandevoorde (2007) extensively reviewed the accuracy with which the above methods forecast the total project duration, and concluded that SVM generally outperforms other forecasting methods. This is not altogether surprising because SVM is an instantaneous metric, and one continually re-estimates the change in schedule based on the project data to date. This is in agreement with Christensen (1992), who established that the continually updated 3-month averages provided the most reliable estimate of the final cost. This is in contrast to Method #1, which is defined in terms of global quantities, which are assumed constant (*BAC* and *SAC*). However, neither approach defines *how the parameters should evolve over time*, e.g., how does the Earned Schedule evolve over time?

Vanhoucke and Vandevoorde (2007) concluded that graphs of CPI and SPI over time provide valuable information about trends in project performance. When corrective managerial actions are implemented, the changes in the behavior of the indexes are assumed to reflect the impact of management actions. However, since $SPI(t)$ always $\rightarrow 1$ at the end of the project, management cannot claim any credit for the improvement in SPI. Therefore, how does one determine if management actions actually changed the SPI?

We will also make use of labor rate profiles, an approach that was pioneered by Putnam (1978). The Putnam–Norden–Rayleigh curve, now known as PNR, describes the labor *rate* over time for software projects. The PNR curve is well-established and has significant realism. Also, the mathematics is tractable, without too much complexity. The PNR curve does not work so well for projects that are incrementally developed (Conte et al., 1986).