PROJECT PERFORMANCE REPORTING AND PREDICTION: EXTENSIONS OF EARNED VALUE MANAGEMENT

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─Abstract ─

Earned Value Management is one of the best known approaches to project progress control and reporting. It uses information on cost, schedule and work performance to establish the current status of the project. By means of a few rates it allows the manager to extrapolate current trends on the project outcome. However, the method bases on a much simplified model of the project, the input is reported to be laborious to collect, and the results may be misleading. The paper outlines the basic principles of the method and discusses its recent modifications aimed at improving reliability in describing project status, expanding predictive ability, and allowing for risk control.

Key Words: *Earned Value, Project Control, Progress Reporting*

JEL Classification: M11

1. INTRODUCTION

1.1. S-curves

S-curves are used in project management worldwide and for nearly one hundred years: records of their practical application can be traced back to 1928 (Martyniak,2002:168). They are representation of "cumulative effort" related with the project plotted against time. This effort is expressed in the same units for all tasks the project comprises, usually man-hours (labour consumption) or monetary units (cost or payments). Comparing the "as planned" S-curve with records of actual effort, if done on regular basis, enables the manager to follow the development of the project. S-curves are used both in the form of charts (to provide a one-glance insight into project performance) or tables (for easy data manipulation). However, S-curves are a far going generalization of the modelled project. Interpreting them with no regard to the relationships between project tasks and reasons for deviations may lead to wrong decisions. In spite of this, S-curves do not lose on popularity in management, and one of their most common application is Earned Value – a method designed to provide reliable measures of project performance and to allow the manager to make inferences on the final effect of the project (PMI,2005:1).

1.2. Earned Value

Earned Value is widely accepted as a classic management tool used for reliable progress reporting and process control. It is the core of management systems used by many public and government organisations, especially in English-speaking countries (DOD,1997) (DOE,2008), and is described by numerous national standards, e.g. (AS,2006) (ANSI,1998).

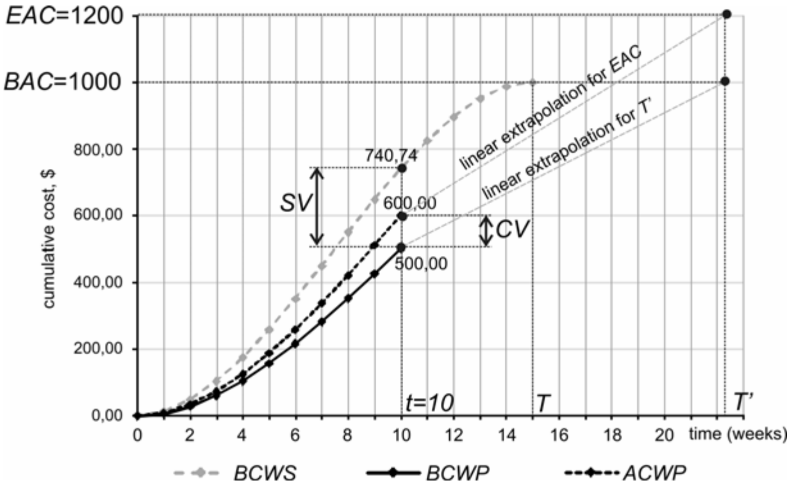
The idea of Earned Value consists in constructing a baseline, against which actual progress will be checked; the baseline is Budgeted Cost of Works Scheduled (*BCWS*) i.e. the S-curve of cumulative planned costs, shown against planned time of their incurrence (Figure 1). *BCWS* is based on the budget broken down into manageable, clearly defined tasks. At completion (*T*), the value of *BCWS* equals the total planned cost of the whole project, Budget at Completion (*BAC*). As the project starts, careful monitoring of actual task progress and task cost is being made on regular basis. Two more S-curves are produced (PMI,2005:8)

- Budgeted Cost of Work Performed (*BCWP*) – the sum of as-planned cost of tasks actually done up to the moment of performance check; compared with the baseline, *BCWS*, it serves as a measure of physical progress of works;

- Actual Cost of Work Performed (*ACWP*) – the sum of incurred cost of works actually done up to the moment of performance check; compared with *BCWP* (as it concerns actually completed works, not as-planned works as *BCWS*) will provide information on deviation from the budget.

The input having been collected, project status indicators can be calculated and current project development tendencies can be extrapolated to give the manager the prospects of possible final effect of the project. The idea is illustrated by an example in figure 1.

Figure-1: Earned Value curves; the project is currently (at week 10) over budget and behind schedule



Percent Complete (*PC*) is the level of scope completion at the moment of progress check, a figure that may be particularly useful in reporting:

$$PC = \frac{BCWP}{BAC}.$$

Cost Variance (*CV*) is a measure of deviation between the budgeted and the actual cost of works actually completed up to the date of progress check, expresses in monetary units. If negative, it indicates that the project is over budget:

$$CV = BCWP - ACWP.$$

Cost Performance Index (*CPI*) also compares the planned and actual value of works done. As a relative measure, it is more informative than *CV* in terms of the scale of deviation from the budget. If less than 1, it indicates that the project has consumed more money than planned:

$$CPI = \frac{BCWP}{ACWP}.$$

Schedule Variance (*SV*), though expressed in monetary units, is considered to be the measure of deviation between the actual physical progress of works and their planned progress. It is the difference between the planned cost of work completed and planned cost of work that should have been done by the reporting date. If negative, it indicates a delay:

$$SV = BCWP - BCWS.$$

Like *CV*, the project's *SV* is a sum of *SV*s of particular tasks, so if there are some tasks delayed and some tasks accelerated, *SV* may show no deviation at all. The model is too simple to distinguish between critical and non-critical tasks.

Schedule Performance Index (*SPI*) compares the planned cost of work done with planned cost of work scheduled. *SPI* less than 1 indicates a delay:

$$SPI = \frac{BCWP}{BCWS}.$$

EAC – Estimate at Completion – is an estimate of the effect of deviations accumulated from the project's start on the total project cost. Several formulas are used (PMI 2005:21) (Christensen 1994:17), but one of the most common is based on the project's *CPI* at the date of performance check (PMI 2005:20):

$$EAC = \frac{BAC}{CPI}.$$

A similar rough estimate of the total time required to complete the project, *T'*. can be made using *SPI* and the as-planned duration *T* but, as S-curves do not reflect relationships between tasks and *SPI* bases on deviations in terms on cost, not time, such estimate cannot be considered reliable (PMI 2005:17):

$$T' = \frac{T}{SPI}.$$

3. Improvements of the method

3.1. General overview

There are some serious drawbacks resulting from the fact of reducing a complex system of a project to an extremely simplified, two-dimensional S-curve model. The extensions of the method presented in the following sections are therefore aimed at increasing reliability of performance indicators and making the outputs useful in project control.

3.2. Improving reliability of schedule performance measures

Schedule Performance Index (*SPI*) and Schedule Variance (*SV*) are measures of the level of scope completion, though they are interpreted in terms of delay or acceleration with works. However, after a project is about half completed, these measures cease to be reliable: even if actual productivity drops or rises continuously, the indicators show reduction of the variance from the baseline. On completion, *BCWP=BCWS=BAC*, so *SV*=0 and *SPI*=1 indicating that the project was perfectly on time.

The necessary amendment of this serious flaw came quite recently with the idea of measuring schedule variance (marked *SV(t)*) "horizontally" and expressing it in time units (Figure 2). The new approach was introduced by Lipke (Lipke,2009:402) (Czarnigowska,2008:26) and called Earned Schedule. It uses exactly the same inputs (*BCWS, BCWP*) as Earned Value, and the mathematics behind it (linear interpolation) can be managed by spreadsheet tables (Lipke,2003). This rather obvious add-on to Earned Value, cautiously referred to as an "emerging practice in EVM" (PMI,2005:18) (Davis,2010:4), gains on popularity among the practitioners.

Having established the "horizontal" schedule variance *SV(t)*, one can calculate the "earned schedule" (*ES*), i.e. the period within that the works actually done should have been ready according to the plan – the time-related counterpart of *BCWP* of Earned Value (Figure 2). On this base, time-related schedule performance index *SPI(t)* can be provided:

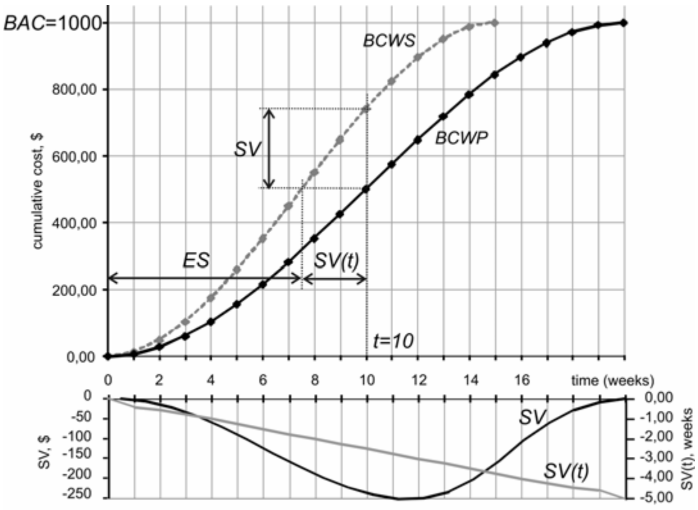
$$SPI(t) = \frac{ES}{t},$$

and finally, a rough estimate of total duration, *T'* (assuming that accrued trend of schedule deviation stays constant):

$$T' = \frac{T}{SPI(t)}$$

Figure 2 presents the record on *BCWS* and *BCWP* of a hypothetical project with a budget *BAC*=$ 1000 and planned duration *T*=15 weeks. The delay trend was constant from the beginning to the actual completion five weeks after the planned deadline (*T'*=20).

Figure-2: Earned Schedule approach to measuring schedule variance. SV calculated by means of spreadsheets by Lipke (Lipke,2003)



Lower part of the chart shows the record of schedule deviation measures: *SV* by classic Earned Value approach and *SV(t)* according to Earned Schedule. The former shows (wrongly) a reduction of delay starting from week 11, whereas the latter reflects the logic of the project development: as the project is steadily carried away from the baseline, the time variance *SV(t)* grows steadily towards the project finish date.

3.3. Improving predictive ability

Earned Value is considered a forecasting tool (PMI, 2005:19). The classic *CPI*-based formula for *EAC* assumes that future costs are going to follow the "today's" pattern. In general, *EAC* formulas in use treat *EAC* as a sum of costs already committed (*ACWP*) and the reminder of the budget adjusted by a factor that reflects the relationship between the project's future and its past (Christensen,1994:17). It is thus clear that *EAC* is a simple linear extrapolation. The calculation does not allow for any future risks or effects of corrective measures, so it is not a proper forecast. However, as the method rests upon systematic progress checks, an early *EAC*-based observation that the project seems to, say, double its cost, would trigger a reaction of the manager early enough to prevent the disaster. The same would refer to Earned Schedule's *SPI(t)*-based estimates of *T'*.

Vanhoucke and Vandervoode (2008:13) applied simulation techniques to a sample of notional 30-task projects networks differing in number of critical activities. This was done to compare predictive ability of Earned Value (*SPI*-based) and Earned Schedule (*SPI(t)*-based) with respect to actual project duration (*T'*). The results confirm that *SPI(t)*-based forecasts are more reliable, and predictions on projects comprising serial activities are more accurate than predictions of projects with many tasks running in parallel.

Analyses of US Department of Defence projects (a sample planned and managed according to specific, formalised and uniformed procedures) led to interesting conclusions (Christensen,2002:105): there occurred to be statistically confirmed rules of cost deviation development. Amongst others, a stabilisation of *CPI* was reported to occur after projects were 20% complete, so *EAC* extrapolations made from this point on can be considered reliable. Generalization of these findings on projects of any size and type may be questioned, but if project performance indicators such as *CPI* and *SPI(t)* developed according to certain patterns, forecasts of similar projects could be considerably improved.

The assumptions on the existence of such patterns led to numerous attempts at improving S-curve based forecasts without scrutinizing schedule network and making task-level risk analysis. Lipke (2009:406), on the basis of patterns found in a small sample of 12 real-life projects, attempted to establish confidence limits for the forecasts made at the moments of consecutive progress checks (*EAC*, *T'*) using statistical methods. The confidence limits were derived from variations of historical period-to-period *CPI* and *SPI(t)* values, respectively.

The patterns of project development were also looked for by means of machine learning techniques. Iranmanesh and Zarezadeh (2008:241) proposed a neural network trained at simulated projects to provide estimates of *ACWP* on the basis of *BCWS* and corresponding *PC*. Neural networks were used also by Rujirayanyong (2009:305) to forecast project completion date; the predictors were: work starting date, date of progress check, contract duration, *PC* and as-planned percent complete, so figures that are available among classic Earned Value inputs. The training sample consisted of real-life road projects. Authors of the above papers claim that neural predictions were more accurate than both classic Earned Value and Earned Schedule predictions. Cheng et al. (2010:619) applied a model based on combination of Support Vector Machine and Fast Messy Genetic Algorithm to predict *EVA* on the basis of historical project data. However, their model required some predictors (like Change Order Index) that are not among classic Earned Value measures.

3.4. Defining "action thresholds"

The performance measures obtained at consecutive progress checks, showing deviation from the baseline, need to be assessed to determine if the scale of deviations is likely to affect the project in negative way and if some preventive actions should be undertaken. Defining "action thresholds" for the project as a whole and for particular tasks is an important element of Earned Value Management (PMI,2005:25). Special care is needed with whole-project measures as, due to the nature of the model, poor performance of some tasks may be (seemingly) compensated by good performance of the other.

Plaza and Turetken (2009:488) combined Earned Value Management with the concept of learning curve to capture changes in performance of project team. The authors claim that the performance at the beginning of the project may be seriously lower than expected and trigger managerial actions – and these may occur excessive as the performance would "naturally" improve with time. The authors provided also a support tool that may improve project duration forecasts.

Lipke (2002:15) and Leu and Lin (2008:813) try to improve search for warning signals by combining Statistical Process Control Techniques with Earned Value and establish the threshold of "natural" project variability on the basis of historic project data. Pajares and Paredes (2010) propose an interesting approach to checking if the variations from the baseline stay within boundaries of variability inherent in the project's probabilistic nature, considered at planning stage by means of detailed risk analysis and allowed for by setting cost and schedule buffers. The buffers are then spread along the project baseline in a way that allows for different sensitivity to risks of different parts of the schedule. The authors allow for changes of these boundaries resulting from project development and managerial decisions taken underway.

4. Conclusions

To some extent, the unfading popularity of Earned Value may be due to its simplicity – manipulation of data requires only four basic arithmetic operations, and the performance indicators produced in the analysis are easy to interpret. However, the "classic" model showed weak points: some performance measures proved unreliable, and forecasting – too simplified. The paper presented an overview of recent works on improving the method and yet keeping it simple. However, regardless of the improvements, the method should be used according to its purpose: it is not a free-standing tool for project outcome forecasting and risk analysis; instead, it simply facilitates monitoring the project status, identification of potentially negative signals and a generalized appraisal of their combined effect on the project's outcome. These signals should be then investigated into by means of more accurate methods, involving in-depth analysis of schedule network relationships.

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