Earned Value Project Management Method and Extensions

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ABSTRACT

The earned value project management method integrates three critical elements of project management: scope management, cost management, and time management. It requires the periodic monitoring of actual expenditures and physical scope accomplishments, and allows calculation of cost and schedule variances, along with performance indices. It allows forecasting of project cost and schedule at completion and highlights the possible need for corrective action.
This paper shows the major aspects of the earned value method and presents graphical tools for assessing project performance trends. It provides logical extensions and useful simplifications to enhance the effective application of this important method in project management.

Keywords: earned value method (EVM); earned value management system (EVMS); cost variance (CV); schedule variance (SV); cost performance index (CPI); schedule performance index (SPI); critical ratio (CR); cost estimate at completion (EAC); time estimate at completion (TEAC)

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Introduction

The earned value project management method is a powerful tool that supports the management of project scope, time, and cost. It allows the calculation of cost and schedule variances and performance indices, and forecasts of project cost and schedule at completion. It provides early indications of expected project results based on project performance and highlights the possible need for corrective action. As such, it allows the project manager and project team to adjust project strategy and to make trade-offs based on project objectives, actual project performance, and trends, as well as the environment in which the project is being conducted.

The method uses cost and value as the common measures of project performance for both cost and schedule parameters. It allows the measurement of cost and value in dollars, hours, worker days, or any other similar unit.

This paper shows the major aspects of the earned value method, presents graphical tools that enhance its effectiveness, and provides useful simplifications and logical extensions of this important project management method.

Background

A basic form of the earned value analysis project management method (often referred to as EVA or EVM) can be traced back to industrial engineers on the factory floor in the late 1800s (Fleming & Koppelman, 2000; Kim, 2000). Around 1967, EVM was introduced by agencies of the U.S. federal government as an integral part of the cost/schedule control systems criteria (C/SCSC) and was used in large acquisition programs. EVM has been widely and successfully used in projects associated with the U.S. federal government, with much less reported use in private industry. Use of EVM in private industry and support by popular project management software packages have been limited but have rapidly grown in recent years.

To encourage wider use of EVM in the private sector, the U.S. federal government decided to discard C/SCSC by the end of 1996 and turned toward a more flexible earned value management system (EVMS), also called the earned value project management system (EVPMS). Project Management Institute's *A Guide to the Project Management Body of Knowledge (PMBOK® Guide)* (Project Management Institute, 2000) provided the simplified EVM terminology and formulas.

There has been a high degree of EVM acceptance among current and past users of the method. They tend to agree that EVM can improve cost, schedule, and technical performance of their projects. EVM nonusers indicate that the method is hard to use, that it applies primarily to federal projects, and that they do not need it (Fleming & Koppelman, 2000; Kim, 2000).

This paper simplifies EVM and shows its applicability to public and private sector projects, regardless of size. The paper uses the simplified terminology and provides graphical tools, extensions, and applications of EVM to enhance the use and effectiveness of this important project management method.

EVM Key Components

EVM uses the following project parameters to evaluate project performance:

- **Planned value (PV):** This is the time-phased budget baseline (Figure 1). It is the approved budget for accomplishing the activity, work package, or project related to the schedule. It can be viewed as the value to be earned as a function of project work accomplishments up to a given point in time. This graph of cumulative PV is often referred to as the S-curve (because, with a little imagination, it looks like the letter S, or as an abbreviation of the Spending-curve). This was previously called the budgeted cost of work scheduled (BCWS).

- **Budget at completion (BAC):** This is the total budget baseline for the activity, work package, or project (Figure 1). It is the highest value of PV and the last point on the cumulative PV curve.

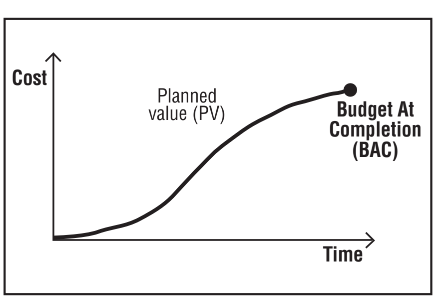

Figure 1. Planned Value and Budget at Completion

- **Actual cost (AC):** This is the cumulative AC spent to a given point in time to accomplish an activity, work package, or project and to earn the related value. This was previously called the actual cost of work performed (ACWP). Figure 2 illustrates a project in which the planned value as of the project status date is PV = $50,000 and the actual cost is AC = $60,000.

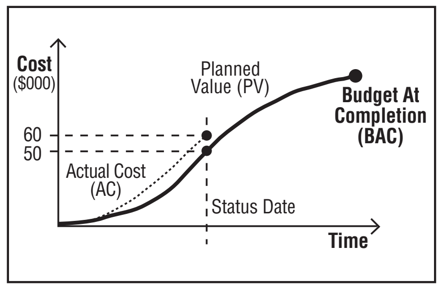

Figure 2. Planned Value and Actual Cost

- **Earned value (EV):** This is the cumulative earned value for the work completed up to a point in time. It represents the amount budgeted for performing the work that was accomplished by a given point in time. This was previously called the budgeted cost of work performed (BCWP). To obtain EV for an item, multiply its total budget by its completed proportion. Table 1 shows the work breakdown structure (WBS) of a project with a total budget of $100,000. Work package 1.1 has a total budget of $20,000 and is 100% complete as of the status date. Therefore, the earned value for this work package is EV = $20,000 x 1.00 = $20,000. Work package 1.2 has a total budget of $40,000 and is 50% complete as of the status date. Therefore, the earned value for this work package is EV = $40,000 x 0.50 = $20,000. The earned value for the entire project is EV = $20,000 + $20,000 = $40,000.

The preceding formula converts project accomplishments from physical units of measure, e.g., cubic yards of concrete, linear feet of cable, percent complete, milestones achieved, or deliverables completed, to financial units of measure. These financial measurements of value can be in dollars (or any other currency), labor hours, work hours, worker days, or any other similar quantity that can be used as a common measurement of the value and cost associated with project work. Figure 3 illustrates the above project, in which the total budget at completion is BAC = $100,000, the planned value as of the status date is PV = $50,000, the actual cost is AC = $60,000, and the earned value is EV = $40,000. These are the main basic entities in EVM.

Performance Measurement

Cost performance is determined by comparing the EV to the AC of the activity, work package, or project. Schedule performance is determined by comparing the EV to the PV. This can be accomplished by calculating the

($000)				
Project		**Budget**	**% Complete**	**Earned Value**
	Phase 1			
	Work Package 1.1	20	100	20
	Work Package 1.2	40	50	20
	....			
	Phase 2			
	Work Package 2.1	...		
	Work Package 2.2	...		
	....	...		
	....	...		
Total		**100**		**40**

Table 1. WBS, Budget, % Complete, and Earned Value

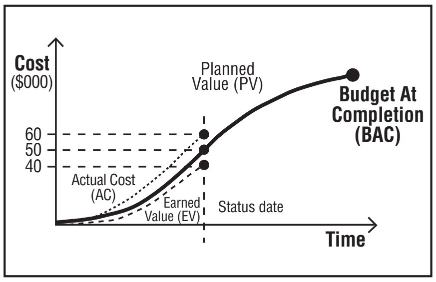

Figure 3. Planned Value, Actual Cost and Earned Value

variances, the variance percentages, and the performance indices at the desired levels of the WBS. It is interesting to note that these comparisons are made to the EV, rather than to the baseline PV.

It is important to synchronize the status date for data in the analysis. This can be accomplished by using the concept of accrued cost, which includes expenditures made but not yet reflected in the financial system, to accomplish work up to the status date.

Variances

The following formulas are used to calculate the variances, generally based on cumulative data, also called inception-to-date data and project-to-date data (Figure 4, using the data from the above project):

The cost variance (CV) is a measure of the budgetary conformance of actual cost of work performed: **CV** = EV – AC. For the above project, CV = \$40,000 – \$60,000 = -\$20,000.

The schedule variance (SV) is a measure of the conformance of actual progress to the schedule: **SV** = EV – PV. For the above project, SV = \$40,000 – \$50,000 = -\$10,000.

Time variance: The average AC per time period is often called the spend rate or burn rate. Similarly, the average PV per time period can be called the planned accomplishment rate, planned value rate, or the PV rate. It is defined as the baseline BAC divided by the baseline schedule at completion (SAC). As a formula, **PV Rate** = BAC / SAC. Thus, SV can be translated into time units by dividing SV by the PV Rate. The result is the SV in time units or the TV. As a formula, **TV** = SV / PV Rate. If the above project were scheduled for forty weeks, then:

PV Rate = \$100,000 / 40 = \$2,500 per week

TV = -\$10,000 / \$2,500 = -4 weeks

TV measurement also can be performed and reported graphically. This is accomplished by drawing a horizontal line from the intersection of the EV curve with the status date to the PV curve and reading the distance on the horizontal time axis (Fleming & Koppelman, 2000), as shown in Figure 4.

In the above formulas, 0 indicates that performance is on target. A positive value indicates good performance. A negative value indicates poor performance.

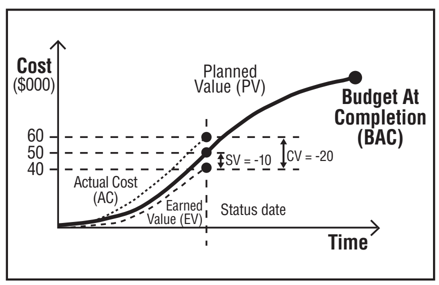

Figure 4. Variances

Graphical Displays

Graphs of variances over time provide valuable indicators of trends in project performance and of the impact of any corrective actions (Figures 5 and 6).

Variance Percentages

The following formulas are used to calculate the variance percentages, generally based on cumulative data (Figure 4, using the data from the above project):

The cost variance percent (CV% or CVP) is a measure of the budgetary conformance of actual cost of work performed: **CVP** = CV / EV. For the above project, CVP = -\$20,000 / \$40,000 = -50%, which indicates that the project is 50% over budget.

The schedule variance percent (SV% or SVP) is a measure of the conformance of actual progress to the schedule. The following formula has been generally used to calculate it (Project Management Institute, 2000): **SVP** = SV / PV.

For the above project, SVP = -\$10,000 / \$50,000 = -20 %. This means that the project is 20% behind schedule.

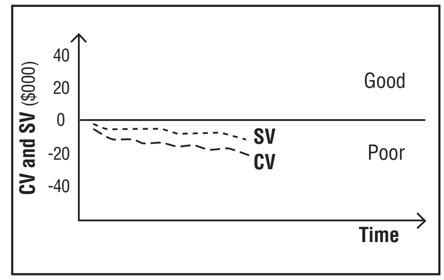

Figure 5. CV and SV Graph

However, it may be appropriate to use EV rather than PV in the denominator of this formula (J. J. Moder in Cleland & King, 1988). The SVP based on the earned value (SVev% or SVPev) would be defined as: SVPev = SV / EV. For the above project, SVPev = -\$10,000 / \$40,000 = -25%. This indicates that the project is 25% behind schedule.

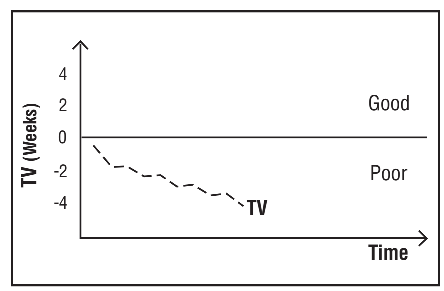

Figure 6. TV Graph

SVP_{ev} is consistent with the formula for CVP. It points out that SV occurred while accomplishing EV. Therefore, it may be a better indicator of project schedule status, as shown later in the calculation of the time estimate at completion (TEAC).

In the above formulas, 0 indicates that performance is on target. A positive value indicates good performance. A negative value indicates poor performance.

Performance Indices

The following formulas are used to calculate the performance indices, generally based on cumulative data (Figure 4, using the data from the above project):

The cost performance index **(CPI)** is a measure of the budgetary conformance of actual cost of work performed: CPI = EV / AC. For the above project, CPI = $40,000 / $60,000 = 0.67.

The schedule performance index **(SPI)** is a measure of the conformance of actual progress to the schedule: SPI = EV / PV. For the above project, SPI = $40,000 / $50,000 = 0.80.

Performance indices can be thought of as efficiency ratios. In the above formulas, 1.00 indicates that performance is efficient and on target. More than 1.00 indicates excellent, highly efficient performance, and less than 1.00 indicates poor, inefficient performance.

The inverse of the formulas given above has also been used (Anbari, 1980; Egan, 1982; Cioffi, 2002; Webster, 2002). This facilitates use of the indices in forecasting. Using the inverse definition, the CPI for the above project would be $60,000 / $40,000 = 1.50, indicating that the project is running 50% over budget. Completion of the project would be forecasted at $150,000, if performance continues at this rate. Similarly, the SPI would be $50,000 / $40,000 = 1.25, indicating the project is running 25% behind schedule. The project would be forecasted to take 25% longer than the original schedule, with completion at 1.25 x 40 weeks = 50 weeks, if performance continues at this rate. These forecasts are discussed in more detail in the forecasting section of this paper.

Graphs of performance indices over time provide valuable indicators of trends in project performance and the impact of any corrective actions. These graphs can be very effective in project reviews (Figure 7).

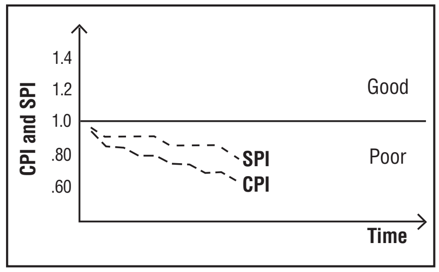

Figure 7. CPI and SPI Graph

The Critical Ratio

The critical ratio (CR) is the product of CPI and SPI (Anbari, 2001; Lewis, 2001). It can also be called the cost-schedule index (CSI) (Barr, 1996; Meredith & Mantel, 2000). It is used as an indicator of the overall project health: **CR** = CPI x SPI. For the above project, CR = 0.67 x 0.80 = 0.53.

A CR of 1.00 indicates that the overall project performance is on target. This may result from both CPI and SPI being close to target, or, if one of these indices suggests poor performance, the other must be indicating good performance. This allows some trade-offs to reach the desired project goals.

A CR of more than 1.00 indicates that the overall project performance is excellent. This may result from both the CPI and SPI being better than target, or, if one of these indices is indicating poor performance, the other must be indicating outstanding performance. This allows extensive trade-offs to reach the desired project goals.

A CR of less than 1.00 indicates that the overall project performance is poor. This may result from both the CPI and SPI being worse than target, or, if one of these indices suggests good performance, the other must be indicating extremely poor performance. This limits the use of effective trade-offs, and highlights significant difficulty in attempting to reach the desired project goals.

A graph of the critical ratio over time provides a quick indicator of trends in the overall project performance, and of the impact of any corrective actions. These graphs may be very effective in project reviews (Figure 8).

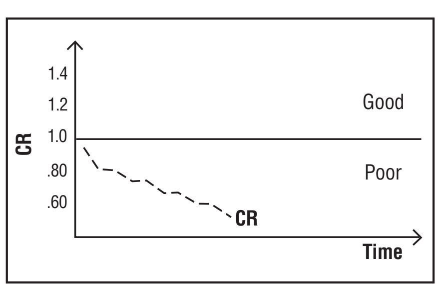

Figure 8. CR Graph

Quantifying the Traffic Light Approach

Graphs of CPI, SPI, and CR can be used to further highlight these measures of project performance and to quantify the "traffic light approach." We can include the line that indicates on target performance with the area that indicates good performance and use the color green to indicate on target and good (better than target) performance. We can break the poor performance area into two and use the color yellow to indicate somewhat below target performance, and the color red to indicate poor performance. It is important for the organization to carefully establish meaningful thresholds, acceptable tolerances, or critical limits for action on project performance. This helps ensure that when action is needed, it is highlighted, and when action is not needed, tampering and micromanagement are minimized.

For example, performance indices and critical ratios of 1.00 or above can be considered green; performance indices and critical ratios equal to or greater than 0.80, but less than 1.00, can be considered yellow; and performance indices below 0.80 can be considered red. In this paper, a black and white chart depicting this concept is shown in Figure 9, and is called the target performance chart. It can be produced in color and may also be nicknamed the rainbow chart.

Other colors can also be added. For example, orange or amber can be used between yellow and red, or in the yellow area to indicate that the item in trouble has been previously reviewed. Blue can be used to indicate the superstars—items with performance indices above 1.20, for example (Figure 9). Some may say that such superstar items must have had inflated baseline budgets and schedules. However, there may be important lessons to be learned from these items in terms of estimating, budgeting, performance management, and cost control. Reallocation of organizational resources may be another outcome from such analyses (Lewis, 2001).

An activity, work package, or project should be carefully reviewed when it enters the yellow zone, with the intent of finding the root cause(s) of performance or planning problems and eliminating them. When an item in the red zone is reviewed, this should generally be a status report on action(s) taken or not taken when that item was in the yellow zone. When an item enters the blue zone, it also would be appropriate to review it, to obtain information on the root cause(s) of the super performance, and incorporate the lessons learned into future work.

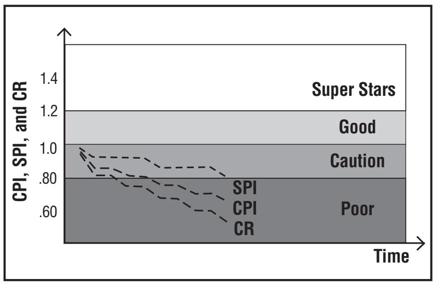

Figure 9. Target Performance Chart

Forecasting

Project management is primarily concerned with decisions affecting the future. Therefore, forecasting and prediction are extremely important aspects of project management. EVM is particularly useful in forecasting the cost and time of the project at completion, based on actual performance up to any given point in the project.

Forecasting of Cost at Completion

The EAC may also be called cost estimate at completion (CEAC). The estimated cost to complete the remainder of the project is usually called the estimate to complete (ETC). Both can be developed using various cost estimating methods or calculated mathematically using EVM.

EACs may differ based on the assumptions made about future performance. The *PMBOK® Guide* (Project Management Institute, 2000) provides three such estimates, based on three different assumptions. In this section, these estimates are reviewed, simplified and enhanced. They are given a sequential subscript to differentiate among them.

When current analysis shows that the assumptions underlying the original estimate are flawed, or no longer applicable due to changed conditions affecting the activity, work package, or project, a new ETC needs to be developed; EAC1 is the sum of the cumulative AC plus the ETC. As a formula, **EAC_1** = AC + ETC. For the example project used in this paper, EAC_1 = \$60,000 + ETC. This applies where ETC is developed for the remaining work. EAC_1 may also be called the revised cost estimate (RCE), latest revised estimate (LRE), or current working estimate (CWE).

Using the above assumption, the ETC for the remainder of the activity, work package, or project usually is developed using various cost estimating methods. Because the work already is in progress, a detailed, bottom-up cost estimate for the remaining work is common in this case.

When current analysis shows that past performance is not a good predictor of future performance, that problems or opportunities which affected performance in the past will not occur in the future, and that future performance will parallel the original plan, the EAC_2 is the sum of the cumulative AC plus the original budget for the remaining work (BAC – EV): **EAC_2** = AC + BAC – EV. For the above project, EAC_2 = \$60,000 + \$100,000 – \$40,000 = \$120,000.

The above formula can be simplified as follows:

$$\begin{aligned} \mathbf{EAC_2} &= AC + BAC - EV \\ &= BAC + (AC - EV) \\ &= BAC - (EV - AC) \\ &= BAC - CV \end{aligned}$$

Thus:

$$\mathbf{EAC_2} = BAC - CV$$

The definition of EAC_2 can therefore be simplified to equal the original baseline BAC minus the CV. For the above project, EAC2 = \$100,000 – (-\$20,000) = \$100,000 + \$20,000 = \$120,000.

Using the above assumption, the ETC for the remainder of the activity, work package, or project is the original budget for the remaining work (BAC – EV).

When current analysis shows that past performance is a good predictor of future performance, that performance to date will continue into the future, and that efficiencies or inefficiencies observed to date will prevail to completion, the EAC_3 is the sum of the cumulative AC plus the original budget for the remaining work (BAC – EV), modified by a performance factor, which is usually the cumulative CPI. As a formula, **EAC_3** = AC + (BAC – EV) / CPI. For the above project:

$$\begin{aligned} \mathbf{EAC_3} &= \$60{,}000 + (\$100{,}000 - \$40{,}000) / 0.67 \\ &= \$60{,}000 + \$60{,}000 / 0.67 \\ &= \$60{,}000 + \$90{,}000 \\ &= \$150{,}000 \end{aligned}$$

The above formula can be simplified as follows:

$$\begin{aligned} \mathbf{EAC_3} &= AC + (BAC - EV) / CPI \\ &= AC + BAC / CPI - EV / CPI \\ &= AC + BAC / CPI - AC \\ &= BAC / CPI \end{aligned}$$

Thus:

$$\mathbf{EAC_3} = BAC / CPI$$

The definition of EAC_3 can therefore be simplified to equal the original BAC divided by the CPI. For the above project, EAC_3 = \$100,000 / 0.67 = \$150,000. EAC_3 may also be called the statistical estimate at completion (EAC_{stat}), the mathematical estimate at completion (EAC_{math}), or simply the cost at completion (CAC).

Using the above assumption, the estimated cost to complete the remainder of the activity, work package, or project is the original budget for the remaining work divided by the CPI. As a formula, **ETC** = (BAC – EV) / CPI. This may be called statistical estimate to complete (ETCstat) or the mathematical estimate to complete (ETCmath).

A graph of the EAC over time provides a valuable indicator of trends in project cost performance and the impact of any corrective actions. This graph can be particularly effective in project reviews. Figure 10 shows a graph of EAC for the example project used in this paper, using the above assumption.

Additional Forecasts of Cost at Completion

Other assumptions can be made about future performance and may result in different estimates at completion. In this section, other assumptions and the resulting EACs are presented. They

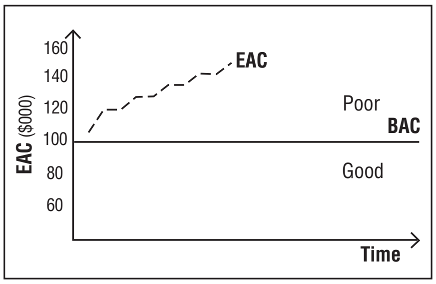

Figure 10. EAC Graph

are given a continuing sequential subscript to differentiate among them.

In some organizations, it is common to state that the activity, work package, or project will meet the original targets upon completion, regardless of prior performance. This frequently occurs early in the project when prior performance has been poor. The EAC_4 would be the original baseline BAC. As a formula, $\mathbf{EAC_4}$ = BAC. Statements such as the following may be heard: "We had some mobilization problems, but we took care of them. We expect the project to finish on schedule and on budget." or "The original specs were unclear. So we took additional time to clarify them. We are planning to meet project targets at this time."

The above statements should be challenged firmly, with a response such as: "What we hear you say is that future performance will be so much better than the original plan and will make up for prior cost overruns (and delays). So far, we have not performed to the original plan and would like to know how this superior performance will be achieved."

EAC_4 is rarely achieved. Unmanaged projects do not fix themselves. They only tend to overrun their budgets, fall behind their schedules, and often miss other scope and quality targets.

Heinze (1996) provides the following additional formula for calculating the EAC: EAC = BAC / CPI x SPI. Fleming & Koppelman (2000) provide a similar formula and support it by indicating that there is a human tendency to get back on schedule, even if that requires more resources for the same work. The above formula may be mathematically questionable. However, it acknowledges that cost management and schedule management are inseparable (Kerzner, 2001). As examples: Project schedules can be crashed at an additional cost, or less skilled resources may be used on the project, which may reduce the cost and possibly extend the duration.

The assumption implied by the above formula is that if the activity, work package, or project were behind schedule, additional cost would be incurred to bring the project back on schedule, through the use of overtime, additional resources, expediting shipments, and similar actions. On the other hand, if the activity, work package, or project were ahead of schedule, opportunities for significant cost savings may be pursued, although they may require more time as a result of using resources that are fewer in number, less experienced, and/or less skilled. Additional time may also be required to find better prices for equipment and material, negotiate better contract terms, use more economical shipping methods, or take similar actions. This formula may provide a better indication of estimated cost at completion, when adherence to a schedule is critical to the organization.

Using the earlier definition of CR = CPI x SPI, and further defining EAC_5 or EACs as the EAC adjusted for schedule performance, the above formula can be restated as follows: $\mathbf{EAC_5}$ = $\mathbf{EAC_s}$ = BAC / CR. For the above project, EAC_5 = EACs = \$100,000 / 0.53 = \$187,500.

Using the above assumption, the ETC for the remainder of the activity, work package, or project is the original budget for the remaining work divided by the CR: (BAC – EV) / CR. This may be called the ETC adjusted for schedule performance (ETC_s). A graph of the EAC_s over time provides a valuable indicator of trends in project cost performance and the impact of any corrective actions. This graph can be very effective in project reviews. Figure 11 shows a graph of EAC_s for the example project used in this paper, using the above assumption.

A case that is not often mentioned occurs when the EAC_6 is substantially higher than the original baseline BAC. As a formula, $\mathbf{EAC_6}$ >> BAC. This estimate is generally not quantified, but is referred to by project team members with statements such as: "If you think this is bad, wait till you see the next report! You ain't seen nothing yet!" or "The cost is going sky high. If this project ever finishes, it would be a miracle!"

This case may result from delaying corrective action and believing for too long that the actual cost at completion somehow would end up close to the original baseline BAC, regardless of prior poor performance. Higher costs, lower levels of accomplishment, and inefficient spending patterns become practically irreversible and the project's fate is sealed. Statistics of challenged and failed projects testify that this case is much more common than we would like to believe.

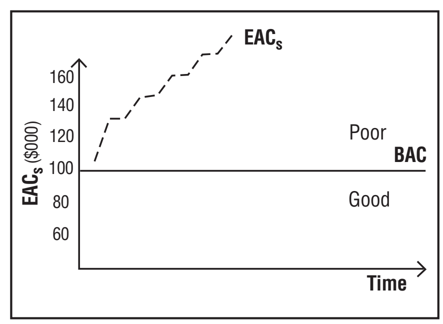

Figure 11. EAC_s Graph

The Standish Group conducted surveys and interviews to explore what causes information technology (IT) software development projects to be challenged and why these projects fail. These studies classified projects into three types:

Successful: The project is completed on time and on budget, with all features and functions as originally specified;

Challenged: The project is completed and operational but is over budget, beyond the time estimate, and offers fewer features and functions than initially specified;

Failed: The project is canceled before completion.

The Standish Group study conducted in 1994 and published in 1995 (The Standish Group, 1995) had a total sample of 365 respondents representing 8,380 projects. The results of that research showed that 16% of IT projects were successful, 53% were challenged, and 31% failed. Comparisons to subsequent studies are shown in Table 2 (The Standish Group, 1999):

Year of Study	Successful	Challenged	Failed
1994	16%	53%	31%
1996	27%	33%	40%
1998	26%	46%	28%

Table 2. Project Resolution HIstory

The Treasury Board of Canada Secretariat (2000–2002) supported findings of The Standish Group, indicated similarities to results of reviews of Canadian government IT projects and presented a framework for the management of these projects.

A survey of IT projects by Sauer and Cuthbertson (2002) covered various industry sectors and government in the United Kingdom, and had a usable sample size of 565 projects. It showed that 5% of all projects were reported to have been abandoned prior to or during implementation, 55% of projects exceeded budget, 27% came in exactly on budget, and 8% came in below budget. Performance, measured by attainment of initially agreed upon specifications, averaged above 80%. Across the whole sample, 56% delivered 90% to 99% of the specifications, approximately 20% of projects delivered less than 80% of the specifications, and a sprinkling of projects exceeded the specifications.

Variance at Completion:

The variance at completion (VAC) gives an indication of the estimated cost underrun or overrun at the completion of the project. As a formula, **VAC** = BAC – EAC. For the above project, using BAC = 100,000 and EAC3 = 150,000, VAC = 100,000 – 150,000 = -50,000.

In the above equation, 0 indicates that the project is forecasted to be completed on budget. A positive value indicates a forecasted underrun. A negative value indicates a forecasted overrun.

A graph of the VAC over time provides a valuable indicator of trends in project cost performance and the impact of any corrective actions. This graph can be effective in project reviews. Figure 12 shows a VAC graph for the example project used in this paper, using the above assumption.

Completion Time Forecasting

EVM has not been widely used to estimate the total time at completion, total project duration, or schedule for an activity, work package, or project based on actual performance up to a given point in the project. However, using assumptions and logic similar to those discussed above, the project's time estimate at completion (TEAC) and time variance at completion (TVAC) can be calculated based on the baseline schedule at completion (SAC) and actual performance up to any given point in the project (Anbari, 2001 and 2002).

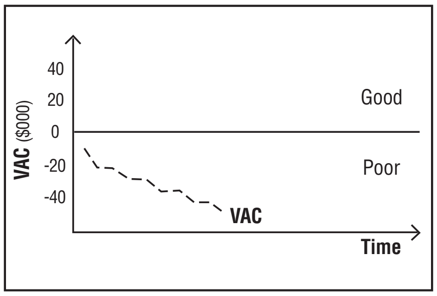

Figure 12. VAC Graph

In this section, various time estimates are presented and given a sequential subscript to differentiate among them, following the same pattern used previously for the cost estimate at completion.

When current analysis shows that assumptions underlying the original time estimate were flawed or no longer applicable due to changed conditions affecting the activity, work package, or project, a new schedule, duration estimate, or time estimate to complete (TETC) needs to be developed, and the $\mathbf{TEAC_1}$ is the sum of the cumulative AT plus the TETC. As a formula, $TEAC_1$ = AT + TETC.

The example project used in this paper has an original baseline SAC of 40 weeks, and its status date is 20 weeks, meaning that the cumulative AT is 20 weeks. Therefore: $TEAC_1$ = 20 + TETC weeks. In this case, TETC needs to be developed for the remaining work. $TEAC_1$ may also be called the revised schedule or current schedule.

When current analysis shows that past schedule performance is not a good predictor of future schedule performance, that problems or opportunities which affected schedule performance in the past will not occur in the future, and that future schedule performance will parallel the original plan, $TEAC_2$ is the sum of the cumulative AT plus the original scheduled time for the remaining work. This can be simplified to the original baseline SAC minus the TV (Fleming & Koppelman, 2000). As a formula, $\mathbf{TEAC_2}$ = SAC – TV. For the above project, $TEAC_2$ = 40 – (-4) = 40 + 4 = 44 weeks.

The above is the total estimated schedule duration that would have been obtained using the critical path method (CPM) or the program evaluation and review technique (PERT), if the schedule slippage of four weeks were on the critical path.

When current analysis shows that past schedule performance is a good predictor of future schedule performance, that performance to date will continue into the future, and that schedule efficiencies, or inefficiencies, observed to date will prevail to completion, $TEAC_3$ is the sum of the cumulative AT plus the original scheduled time for the remaining work, modified by the cumulative SPI. This can be simplified to the original baseline SAC divided by the SPI. As a formula, $TEAC_3$ = SAC / SPI. For the above project, $TEAC_3$ = 40 / 0.80 = 50 weeks.

The above example indicates that the project is estimated to be completed 25% behind schedule: (40 weeks – 50 weeks) / 40 weeks = -10 weeks / 40 weeks = -0.25 = -25%.

A graph of the TEAC over time provides a valuable indicator of trends in project schedule performance and the impact of any corrective actions. This graph can be effective in project reviews. Figure 13 shows a graph of TEAC, for the example project used in this paper, using the above assumption.

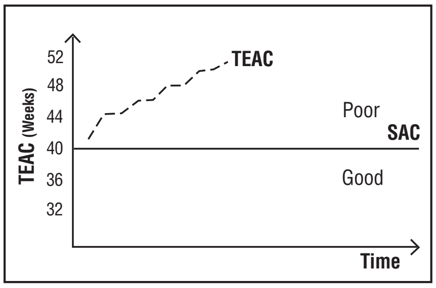

Figure 13. TEAC Graph

In some organizations, it is common to state that the activity, work package, or project will be on schedule upon completion, regardless of prior performance. This frequently occurs early in the project, when prior schedule performance has been poor. The $TEAC_4$ would be the original baseline SAC. As a formula, **$TEAC_4$** = SAC. Statements similar to those mentioned earlier in the cost discussion may be heard. In some disciplines, such as software development, it is common to conclude these statements saying, "We'll catch up during the testing phase!" Several modifiers to the word "test" have been developed, which may increase the likelihood of catching up. They include: alpha test, beta test, user test, stress test, acceptance test, and parallel test. Such statements should be challenged firmly, with a response similar to that mentioned earlier in the cost discussion.

$TEAC_4$ is rarely achieved. Again, unmanaged projects do not fix themselves. They only tend to fall behind their schedules, overrun their budgets, and often miss other scope and quality targets.

Recalling that cost performance and schedule performance are inseparable, the assumption can be made that if an activity, work package, or project were running over budget, additional time may be needed to bring the project back on budget. This may be accomplished by reducing resources applied to the project, using fewer paid resources, many of which are less experienced and less skilled, taking additional time to find better prices for equipment and material, negotiate better contract terms using more economical shipping methods, and similar actions. On the other hand, if an activity, work package, or project were running below budget, opportunities for reducing completion time, reducing cycle time, and expediting time to market may be pursued, although they may incur more cost. This may be accomplished through the use of overtime, additional resources, and expediting shipments.

Defining $TEAC_5$ or $TEAC_c$ as the TEAC adjusted for cost performance, the following formula would reflect the above assumption: **$TEAC_5$ = $TEAC_c$** = SAC / CR. For the above project, $TEAC_5$ = $TEAC_c$ = 40 / 0.53 = 75 weeks. This formula may provide a better indication of estimated time at completion, when adherence to budget is critical to the organization. $TEAC_5$ may also be called the time estimate at completion adjusted for cost performance ($TEAC_c$).

A graph of $TEAC_c$ over time provides a valuable indicator of trends in project schedule performance and the impact of any corrective actions. This graph can be very effective in project reviews. Figure 14 shows a graph of $TEAC_c$, for the example project used in this paper, using the above assumption.

A case that is not mentioned often occurs when the $TEAC_6$ is substantially higher than the original baseline SAC. As a formula, **$TEAC_6$** >> **SAC**. This estimate is generally not quantified, but is referred to by project team members with statements similar to those mentioned earlier in the cost discussion. At times, this case occurs in the later phases of a project, when team members have no other planned assignments, and the organization is "right sizing." Quality problems become apparent, and additional time is requested to fix various problems. Sometimes a lot of additional time is needed.

Again, this case may result from delaying corrective action and believing for too long that the project would somehow be completed close to the original baseline schedule, regardless of prior poor performance. Longer durations, lower levels of accomplishment, and inefficient schedule achievement patterns become practically irreversible, and the project's fate is sealed. Statistics of challenged and failed projects testify that this case is much more common than we would like to believe, as previously discussed in the development of EAC_6.

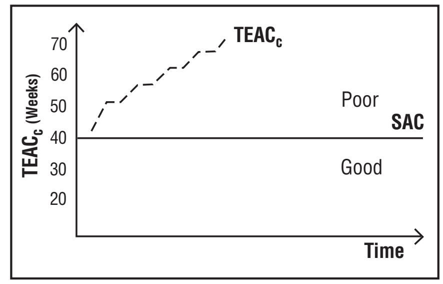

Figure 14. $TEAC_c$ Graph

Time variance at completion: The TVAC gives an indication of the estimated amount of time that the project will be completed ahead or behind schedule: TVAC = SAC – TEAC. For the above project, using SAC = 40 and $TEAC_3$ = 50: TVAC = 40 – 50 = -10 weeks.

In the above equation, 0 indicates that the project is expected to be completed on schedule. A positive value indicates that the project is expected to be completed ahead of schedule. A negative value indicates that the project is expected to be completed behind schedule.

A graph of TVAC over time provides a valuable indicator of trends in project schedule performance and the impact of any corrective actions. This graph can be effective in project reviews. Figure 15 shows a graph of TVAC, for the example project used in this paper, using the above assumption.

CPM, PERT, and EVM

As mentioned above in the development of $TEAC_2$, an underlying assumption of the CPM and the PERT is that future performance will parallel the original plan, unless changes are made to the original plan time, logic, or cost.

The example project used in this

paper has an original baseline SAC of 40 weeks. With a status date of 20 weeks, TV = -4 weeks. If TV represented a schedule slippage of 4 weeks on the critical path, CPM and PERT would estimate a completion time of 44 weeks. This is the same as: $TEAC_2$ = SAC – TV = 40 – (-4) = 40 + 4 = 44 weeks.

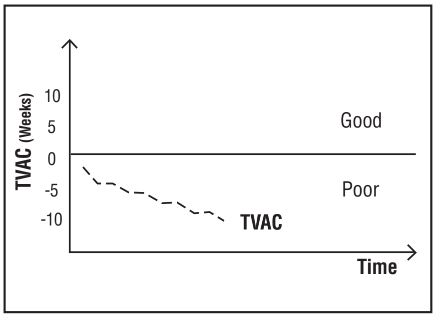

Figure 15. TVAC Graph

CPM and PERT initially assume that problems or opportunities that affected performance in the past will not occur in the future and that past performance is not a good predictor of future performance.

The assumption generally associated with EVM is that past performance is a good predictor of future performance, that performance to date will continue into the future, and that efficiencies or inefficiencies observed to date will prevail to completion. Therefore, the EAC_3 is generally associated with EVM. Similarly, the $TEAC_3$ can be associated with EVM. Therefore: $TEAC_3$ = SAC / SPI = 40 / 0.80 = 50 weeks.

Which of the above forecasts will materialize depends greatly on decisions and actions taken by the project manager, the project team, and the organization. Some like to add luck to the factors affecting project outcomes. Others observe that good luck tends to be directly associated with better planning and better decisions.

Project Forecasting

It is advisable to ask work package managers, project leaders, and functional managers to review cost and schedule mathematical forecasts and to provide their own subjective forecasts for their own work areas in advance of issuing project performance reports and conducting project review meetings. Both mathematical forecasts and subjective forecasts would be included in project performance reports. This effort highlights performance deviations for work area managers, encourages them to consider appropriate, timely actions, and incorporates their close, detailed knowledge of performance in their areas, which may not be evident from the reported values. At a minimum, this effort may help avoid surprises and arguments over the numbers during project review meetings.

Forecasting in project management may well be a self-defeating prophecy, and that may be good for the organization. Large deviations usually attract management's attention and result in corrective action. Small deviations are usually left alone. By quantifying and highlighting such deviations, EVM helps focus management's interest on projects or work packages that need the most attention. As a result, EVM supports effective management of projects and work packages collectively and enhances management of the enterprise's project portfolio (Anbari, 1983). Forecasting using these techniques provides a uniform approach to project reviews, building confidence in the project outcome as time progresses. Changing project evaluation methods during the project duration can result in no meaningful data for decision-making.

Further Extensions, Issues and Applications

Extensions

Using the above definitions, the following is derived (Slemaker, 1985):

% Complete = EV / BAC
% Spent = AC / BAC
Taking the ratio of the above two formulas
(Anbari, 1980):
% Complete / % Spent
= (EV / BAC) / (AC / BAC)
= EV / AC
= CPI
Thus:
CPI = % Complete / % Spent

For the example project used in this paper:

% Complete = \$40,000 / \$100,000
= 0.40 = 40%
% Spent = \$60,000 / \$100,000
= 0.60 = 60%
CPI = % Complete / % Spent
= 40 / 60 = 0.67
The above allows a further simplification
(Slemaker, 1985) of the EAC3:
EAC_3 = BAC / CPI
= BAC / (% Complete / % Spent)
= (BAC x % Spent) / % Complete
= AC / % Complete
Thus: **EAC_3** = AC / % Complete

The definition of EAC_3 can be further simplified to the AC divided by the percent complete. For the above project, EAC_3 = \$60,000 / 0.40 = \$150,000.

Similarly, the $TEAC_3$ can be simplified to: **$TEAC_3$** = AT / % Complete. The example project used in this paper has an original baseline SAC of 40 weeks, and the status date is 20 weeks, which means that the cumulative AT is 20 weeks. Therefore: $TEAC_3$ = 20 / 0.40 = 50 weeks.

Similarly, the following is derived (Anbari, 1980):

CPI = % Complete / % Spent
= (Actual Production / Total Scope) / (Actual Cost / Total Budget)
= (Actual Production / Total Scope) x (Total Budget / Actual Cost)
= (Total Budget / Total Scope) x (Actual Production / Actual Cost)
= (Total Budget / Total Scope) / (Actual Cost / Actual Production)
= Planned Unit Cost / Actual Unit Cost
Thus: **CPI** = Planned Unit Cost / Actual Unit Cost

The additional formulas developed in this section provide a more intuitive understanding of CPI based on information readily available in many organizations. The first formula for CPI uses information widely known in project environments, and the second formula for CPI uses information widely known in production environments:

CPI = % Complete / % Spent

CPI = Planned Unit Cost / Actual Unit Cost

Issues in the Determination of Percent Complete

Determination of the percent complete or proportion complete of an activity, work package, or project is a necessary but challenging task in many organizations. This task becomes even more demanding when dealing with new, emerging, or softer technology projects, such as telecommunications, software development, architectural or engineering design, and research and development.

Alternatives to using the percent complete to determine physical accomplishments have been used. The 50/50 rule specifies that 50% of an item's budget is recorded at the time that the work is scheduled to begin, and the remaining 50% is recorded when the work is scheduled to be completed. If the project had a large number of items, the distortion from the 50/50 rule would be minimal (Kerzner, 2001), because these items would be at various stages of completion. This allows us to calculate PV. Similarly, to calculate EV, 50% of an item's budget is recorded when the work begins, and the remaining 50% is recorded when the work is completed. To make the 50/50 rule work successfully, the project should be broken down into very detailed, short-span work packages (Fleming & Koppelman, 2000).

The 50/50 rule is a common practice in a number of contractual arrangements, such as those for home repair. Half of the contract price is paid up front, and the remaining balance is paid upon completion of the work. It should be noted that when the 50/50 rule is used in a contractual arrangement and the contractor is paid based on this rule, it is reasonable to expect that the contractor will tend to start as many items as possible, collecting 50% of the contract price for each of these items.

The 0/100 rule can also be used. This rule specifies that the value is earned only when the item is completed and is usually used in work packages having a short duration (Kerzner, 2001). This rule can also be called the weighted milestone method, where the value is earned only when the milestone is physically completed, and one or more milestones are planned in each performance-reporting period (Fleming & Koppelman, 2000). Contractors may consider the 0/100 rule harsh. When a contractor is paid based on this rule, it is reasonable to expect that the contractor will strive to have a very detailed WBS that breaks the project down to as many items as possible, so that completion of item(s) can be shown regularly and payment can be authorized.

Other alternatives for determining physical accomplishments can be used. For example, the 10/90 rule, 20/80 rule, and 25/75 rule acknowledge that to start a work package, a certain amount of preparation and mobilization are needed. Therefore, 10%, 20%, or 25% of the value would be considered earned when the work is started, and the remaining amount would be earned when the work is completed. If the work package were front-end loaded, as might be the case with certain equipment acquisitions, then the inverse of these rules might be appropriate. For example, the 75/25 rule might specify that 75% of the value would be considered earned when the equipment is delivered, and the remaining amount is earned when installation, testing, and commissioning are completed.

The percent complete method can be used with a buffer that sets a ceiling of about 80% or 90% upon reported completion. A work package may earn only up to the specified percent ceiling based on subjective estimates. When the work package is 100% complete, the balance is earned. A variation of this approach is using a combination of the percent complete and a milestone gate. A work package may earn only up to a maximum specified percentage of the value associated with the milestone based on subjective estimates. When the predefined, tangible criteria for the milestone are met, the balance of the value associated with the milestone is earned (Fleming & Koppelman, 2000). These approaches may help alleviate the "95% complete and stays there forever" syndrome.

For level of effort items such as project management, customer support, and other support work during a given period of time in a project, the effort itself is the end product. Therefore, the earned value can be considered to be equal to the effort applied or the actual cost.

Applications

EVM provides project managers and the organization with triggers or early warning signals that allow them to take timely actions in response to indicators of poor performance and enhance the opportunities for project success. Such indicators have been found to be reliable as early as 15% into a project. Better planning and resource allocation associated with the early periods of a project might be the cause of this reliability (Fleming & Koppelman, 2000).

EVM can be used for progress payments to contractors based on the EV of contracted or outsourced work. Because such contractual arrangements create legal and financial obligations, it is important to consider the method specified for evaluating progress. The previously discussed alternatives for determination of percent complete should be carefully considered and negotiated to achieve a fair and equitable environment that encourages successful accomplishment of contracted or outsourced project items.

For long-term projects, it may be appropriate to consider incorporating the time value of money and time-discounted cash flows into EVM. Inflation can be explicitly considered in EVM, and the inflation variance (IV) can be calculated (Farid & Karshenas, 1988). However, these considerations add complexity to the method and may be justifiable only for very long-term projects or in very high inflation periods or economies.

An organization may elect to apply EVM uniformly to all of its projects, or only to projects exceeding its own thresholds for cost and schedule reporting and control. EVM can be applied to projects of various types and sizes in the public and private sectors. It can be applied at various levels of a project's WBS and to various cost components, such as labor, material and subcontractors.

Comprehensive Example

A project has a baseline BAC of $100,000 and a baseline SAC of 40 weeks. The baseline indicates that by the end of week 20, the project is planned to be 50% complete. At the end of week 20, it is reported that 40% of the project work has been completed at a cost of $60,000. Using the EVM method:

BAC = $100,000
SAC = 40 weeks

PV = 50% x $100,000
= $50,000
AC = $60,000
EV = 40% x $100,000
= $40,000
AT = 20 weeks

Therefore:

% Complete = EV / BAC
= $40,000 / $100,000 = 40%
% Spent = AC / BAC = $60,000 / $100,000 = 60%

CV = EV – AC = $40,000 – $60,000 = -$20,000
SV = EV – PV = $40,000 – $50,000 = -$10,000

PV Rate = BAC / SAC = $100,000 / 40 weeks = $2,500 per week
TV = SV / PV Rate = - $10,000 / $2,500 per week = -4 weeks

CPI = EV / AC = $40,000 / $60,000 = 0.67
CPI = % Complete / % Spent = 40% / 60% = 0.67
SPI = EV / PV = $40,000 / $50,000 = 0.80

CR = CPI x SPI = 0.67 x 0.80 = 0.53
EAC_3 = BAC / CPI = $100,000 / 0.67 = $150,000
EAC_3 = AC / % Complete = 60,000 / 0.40 = $150,000
VAC = BAC - EAC = $100,000 - $150,000 = -$50,000

EAC_5 = EACs = BAC / CR = $100,000/ 0.53 = $187,500

$TEAC_3$ = SAC / SPI = 40 weeks / 0.80 = 50 weeks
$TEAC_3$ = AT / % Complete = 20 / 0.40 = 50 weeks
TVAC = SAC – TEAC = 40 weeks – 50 weeks = -10 weeks

Conclusion

EVM helps focus management's interest on projects that need most attention and may aid the prioritization and emphasis management gives projects within a portfolio, enhancing the enterprise's project portfolio management. EVM provides important information for project or work package decision-making. Its wider acceptance and effectiveness may depend on better understanding of its capabilities. Simplification of EVM calculations, use of graphical tools to enhance understanding of performance trends, and successful application of EVM in industry are important factors for the growth and effective use of this valuable method in project management.

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