Earned Schedule Leads to Improved Forecasting

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Abstract
For project cost, analysts can predict the final value with some confidence using the Independent Estimate at Completion (IEAC) formulas from Earned Value Management (EVM). The formulas provide a means to understand the financial health of a project without having to reassess the cost value for each of the unfinished tasks. Earned value analysts cannot assess the health of schedule performance in the same manner. EVM does not provide IEAC-like formulas to predict the final duration of a project. Earned Schedule (ES), recently recognized as an emerging practice in the 2005 PMI-CPM EVM Practice Standard, has provided a means for time-based prediction, IEAC(t). This paper will demonstrate that ES extends further into project performance analysis by uniquely connecting the EV accrued to the tasks comprising the performance management baseline. From this connection an additional measure, Schedule Adherence, is created. The new indicator is foreseen to become a valuable prediction measure, leading to better forecasting for both final cost and completion date. Notional data is used to illustrate the improved prediction qualities.

1. Introduction

Earned Value Management (EVM) is a wonderful management method connecting in a very unique way, cost, schedule, and technical performance. It provides capability which facilitates a more scientific approach to project management; i.e. through the use of EVM, project status is now described from numerical evidence. Although this advancement in management method is tremendously significant, EVM has three major deficiencies:

1) *The performance indicators are not directly connected to project output. For example, milestone completion or delivery of products may not meet the customer's expectation, yet EVM indicator values are acceptable.*
2) *The schedule indicators are flawed. For projects completing late, the indicators always show perfect schedule performance.*
3) *The performance indicators are not explicitly connected to appropriate management action. Even with EVM data, the project manager remains reliant upon his intuition as to any action needed.*

The first two deficiencies cited are reasons as to why EVM is generally regarded as a cost management tool; the information relating to schedule performance is inadequate. In fact, there are many knowledgeable users who express the opinion that the prediction of project duration from the use of the schedule indicators is an exercise in futility.

Although there are barriers to having an estimating formula for predicting final project duration from EVM data, it remains a desired capability. Project managers (PM) need the ability to generate reasonable estimates of the duration. Furthermore, they need to be able to estimate a revised completion date at every reporting period without having to exhaustingly evaluate the tasks remaining each time. That is, to manage cost and schedule equally well, PMs need comparable analysis capability for both.

For the remainder of the paper, I'll discuss what is known about project performance. I'll then describe the mechanisms which may cause the behavior. From this foundation, a new performance measure is proposed. The new measure provides the connection of project output to EVM indicators and facilitates the estimation of final project duration.

2. Behavior of the Cost Performance Index

During the 1990s and through 2002, a considerable amount of research was performed concerning the independent estimate at completion (IEAC) formulas and the cost performance index (CPI) from Earned Value Management (see reference [1] for complete description of the various IEAC formulas and EVM indicators) [2,3,4,5,6]. The research, inspired by the cancellation of the Navy's A-12 Avenger acquisition program, focused, primarily, on the accuracy of the various formulas for IEAC. However, some of the studies examined the behavior of CPI over the life of the project.

The studies of CPI are extremely significant to project management. Important observations were made as to how the cost index behaves from the project's beginning until its completion. This behavior explains the findings from the IEAC studies, and validates the use of IEAC = BAC / CPI to predict final cost (BAC is the project Budget at Completion). The CPI study findings are the following:

1) *The result from IEAC = BAC / CPI is a reasonable running estimate of the low value for final cost.*
2) *The cumulative value of CPI stabilizes by the time the project is 20 percent complete. Stability is defined to mean that the final CPI does not vary by more than 0.10 from the value at 20 percent complete.*
3) *The value of CPI tends only to worsen from the point of stability until project completion.*

These results have come from applying methodical statistical testing to as many as 200 large Department of Defense projects. Finding number 2 is established at the statistical confidence level of 95 percent. Thus, in the very early stage of a project, approximately 20 percent complete, the project manager has a good estimate of the high and low bounds of final cost. As the project progresses, the low bound is refined by using the knowledge from finding number 1. Finally, finding 3 indicates that risk impacts tend to occur late in the project; it reminds us to monitor and manage the risks to minimize the worsening of cost efficiency as the project progresses. These are extremely useful PM tools.

3. What causes the Cost Performance Index (CPI) to worsen?

In struggling to answer this question, I began to think about what happens in the execution of the planned project tasks. Early in the project there are many tasks available to work, but as the project moves toward completion the number grows smaller. If impediments occur early, the PM may not take notice because a worker was shifted from the stalled task to another for which he could gain EV. On the other hand, when impediments occur late, there may not be other EV to work. If that is the case, cost efficiency suffers *...and so would schedule performance*. And certainly, the PM will become very aware of the impediment and what effect it is having upon his project's performance.

This deduction, seemingly, is reasonable and the rationale qualitatively explains why the studies observed CPI worsening as EV increased. But, then I wondered, "Do the early impediments cause late impacts, as well?" At first, it wasn't obvious that they might. After some reflection, it became apparent that performing work out of sequence is a likely cause of rework.

When impediments occur early and workers are redirected to perform tasks out of sequence with the plan, I reasoned they must do so at risk. It is a risk because the tasks performed not in accordance with the plan do not have all of the inputs necessary. When inputs aren't fully defined, significant task rework can be expected; the workers are having to fill-in the missing inputs using their own intuition and technical knowledge. When they anticipate well, all is fine; but if not, the task can expect rework, possibly, of the order of 50 percent, or even greater. The rework for the task will appear later in the project and is likely to ripple into subsequent tasks, as it is discovered that functions don't perform as expected.

In general, processes have limitations; i.e., there are bottlenecks or constraints which, when overloaded, limit task progress. The aggregation of rework can overcome the work flow planned in the project schedule and cause overloading of the process constraint. The PM, to keep work flowing when a limiting constraint is encountered, may knowingly shift workers to alternative tasks. By taking this proactive approach, the PM inadvertently creates more rework. At this point it is apparent, rework cascades and causes performance efficiency to suffer, increasingly.

Possibly, these thoughts explain the reason for the exorbitant rework associated with software development projects. *Software development rework is reported to be approximately 40 percent* [7]. Consistent with the preceding discussion this statistic would indicate the developers on the project team frequently vary from the development plan. Or, even worse, it may indicate there is little requirements definition in software development projects and likely, only very cursory project planning and task definition. We know from the March 2004 report prepared by the United States General Accounting Office, *Stronger Management Practices Are Needed to Improve DOD's Software Intensive Weapon Acquisitions*, that these conditions are predominantly true in the software industry [7].

From this correlation of the state of software engineering practice to the cause of rework, we have qualitative confirmation as to why CPI tends to worsen as the project progresses. By induction, it is likewise reasonable to assert that the impact of rework causes the lengthening of schedule, as well. Thus, my hypothesis, derived from the foregoing discussion, is that lack of adherence to the execution of the project schedule is the primary cause for declining performance for both, cost and schedule, as the project moves toward completion. This hypothesis is the foundation for the remainder of the paper.

4. Measuring schedule adherence

The practice today for project managers is to use the EVM cost indicators for managing project cost and the Critical Path for managing schedule performance [8]. Seemingly, they are managed as separate, independent, entities. Everyone knows project cost and schedule are interrelated, but we have no facility to make direct connection between the two. Therefore, PMs have little choice, except to treat cost and schedule separately. *The challenge is to make this connection.*

In order for PMs to better predict project outcomes, a method is needed for understanding schedule progress in a way that is directly connected to earned value data. If this capability can be created, the EVM community will have the "bridge" between cost and schedule, and management tools will become much more integrated than those that exist today. A logical outcome from having increased understanding for the connection between cost and schedule is management of projects should improve and the rate of project successes should increase.

Recall from the introduction at the beginning of the paper, I identified three deficiencies of EVM. The primary focus of most of the discussion thus far is the first one: *EVM is not directly connected to output, or schedule.* The second deficiency of EVM is involved, as well: *the schedule indicators are flawed*. They do not represent schedule performance very well. In fact, it is well known that they fail completely for projects which lag the planned schedule.

The method which overcomes the deficiency of the EVM schedule indicators is Earned Schedule (ES) [9]. Whereas EVM schedule indicators are cost-based, the ES indicators are time-based. The ES indicators are derived from the time association with earned value and the performance management baseline (PMB) as depicted by Figure 1, Earned Schedule Concept.

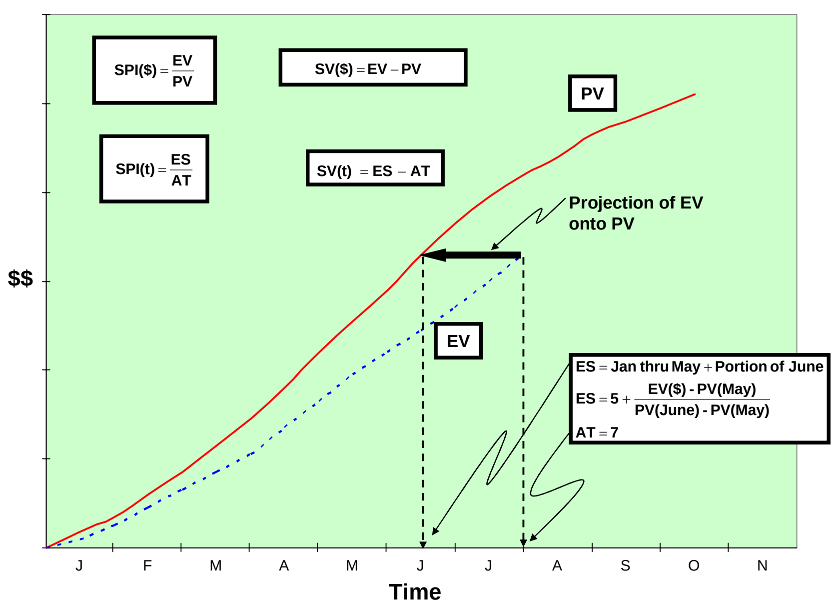

Figure 1. Earned Schedule Concept

The computed value of ES describes where the project should be in its schedule performance. Refer to Figure 2, Earned Schedule - *Bridges EVM to Schedule* (Plan). The figure shows a networked schedule at the top and the project management baseline beneath it. The project status is taken at *AT*, actual time; however, the time performance of the project management baseline is depicted, as shown in Figure 1, by *ES*.

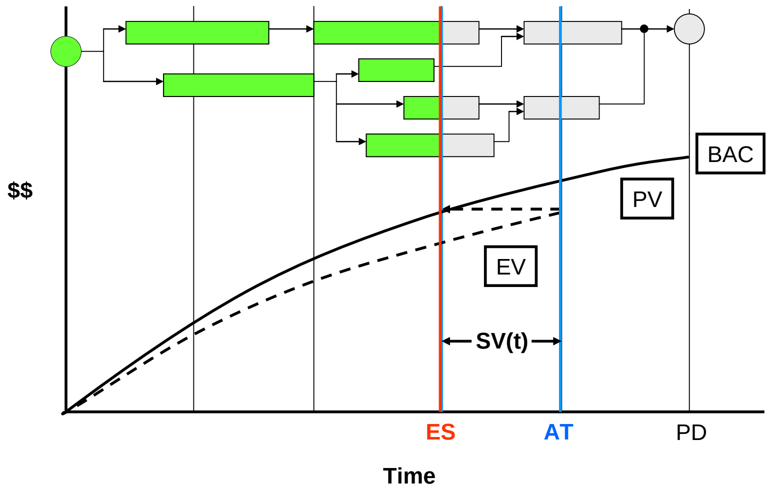

Figure 2. Earned Schedule - *Bridges EVM to Schedule* (Plan)

Earned Schedule provides a remarkable connection between EVM and the schedule. Regardless of the project's actual position in time, we have information describing the portion of the planned schedule which should have been accomplished. Specific tasks make up that portion of the schedule. If the schedule is adhered to we will observe in the actual performance the identical tasks at the same level of completion as the tasks which make up the plan portion attributed to ES. *(The darker shaded areas of the task blocks indicate the completed portions.)*

However, it is more than likely the project is performing as depicted in Figure 3, Earned Schedule – *Bridges EVM to Schedule* (Actual); i.e., EV is not being accrued in accordance with the plan. As seen, the earned value is the same as depicted in figure 2, but the task distribution is different. Figure 3 is a graphical illustration of the previous discussion, *"What Causes CPI to Worsen?"* The lagging performance for tasks to the left of ES indicates the possibility of a constraint or impediment. The EV indicated to the right of ES shows tasks performed at risk; they will likely have significant rework appearing later in the project.

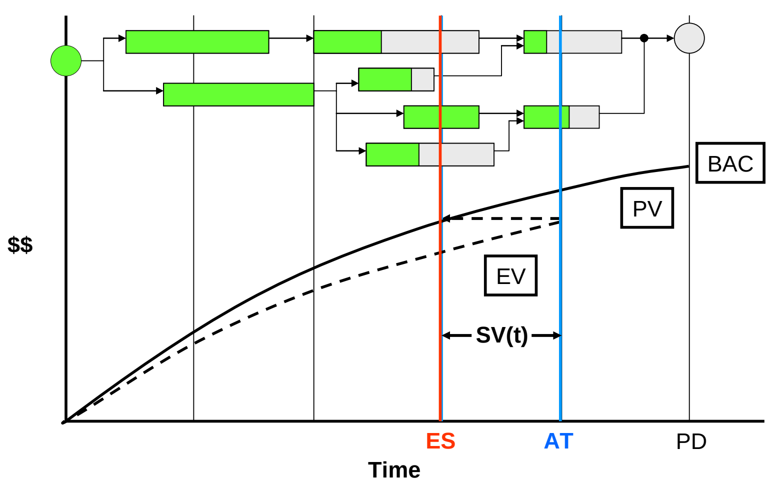

Figure 3. Earned Schedule - *Bridges EVM to Schedule* (Actual)

Both sets of tasks, lagging and ahead, cause poor efficiency. Of course, for the lagging tasks, impediments and constraints make progress more difficult. *Concentrating management efforts on alleviating the impediments will* *have the greatest positive impact on project performance.* The tasks to the right of ES are performed without complete information. The performers of these tasks necessarily create the inputs expected from the incomplete preceding tasks; this consumes time and effort and has no associated earned value.

The preceding discussion describes the need for measuring schedule adherence. By determining the earned value (EV) for the actual tasks performed congruent with the project schedule, a measure can be created. The adherence to schedule characteristic, P, is described mathematically as a ratio:

$$P = \Sigma\, EV_j / \Sigma\, PV_j \qquad (1)$$

PV_j is the planned value for tasks associated with ES, and EV_j is the earned value at AT (actual time) corresponding to and limited by the planned tasks, PV_j.

A characteristic of the P-Factor is that its value must be between zero and one; it cannot exceed one. A second characteristic is that at project completion it will exactly equal 1.0.

5. Making use of the P-Factor

When the value for P is much less than 1.0, the project manager (PM) has a strong indication the project is experiencing an impediment, the overload of a constraint, or the workforce has poor process discipline. The PM thus has an indicator which enhances the description portrayed by EVM.

To understand how P can be used beyond its qualitative application, let us begin by identifying some fundamental relationships:

- Cumulative EV @ AT = EV $=\Sigma\, EV_i$ @ AT $= \Sigma\, PV_j$ @ ES (2)
  where ΣEV_i includes all of the tasks completed or in work

- EV earned in accordance with the schedule: $EV(p)= \Sigma EV_j$ @ $AT = P * EV$ (3)
  where the subscript j identifies the planned tasks associated with ES

- EV earned not in accordance with the schedule: $EV(r) = EV - EV(p) = (1 - P) * EV$ (4)

The preceding definitions are extremely important to the remainder of the paper. As further explanation, the tasks planned to be completed or in work (i.e. those tasks in agreement with the schedule) are left of the ES line. The positioning of the ES line represents the earned duration of the project management baseline. This calculated value of ES thus identifies tasks completed and amount of in-work accomplishment in accordance with the schedule. The identified set of planned tasks, in turn, identifies which of the performed tasks are used for calculating EV(p); i.e., the sum of EV_j for the tasks in consonance with the schedule. The EV_j for the performed tasks is limited to the PV_j at the duration equal to ES. It may be worth repeating at this point that the tasks lagging the planned performance at ES likely have constraints or impediments and those where actual performance exceeds the plan can expect future rework.

Now, let us examine the impact of rework. Recall, a portion of EV(r) is unusable and requires rework. Therefore, we need to determine the usable portion in terms of percentage of rework (R%):

- R% = unusable fraction of EV(r) / usable fraction of EV(r) $= f(r) / f(p)$ (5)
  where $f(p) + f(r) = 1$
- Substituting for f(r): $f(p) + R\% * f(p) = 1$ (6)
- Solving for f(p), we obtain: $f(p) = 1/(1 + R\%)$ (7)

Finally, with these relationships we can calculate the earned value which effectively moves the project toward completion:

- Effective EV = EV(e) = EV(p) + usable portion of EV(r) $= EV(p) + f(p) * EV(r)$ (8)

- $EV(e) = EV(p) + [1 / (1 + R\%)] * EV(r)$
  $= P * EV + [1 / (1 + R\%)] * [(1 – P) * EV]$
  $= [P + \{(1 – P) / (1 + R\%)\}] * EV$

- $EV(e) = [(1 + P * R\%) / (1 + R\%)] * EV$ (9)

Thus, it is determined that the plan adherence (P-Factor), along with rework, and cumulative earned value determine the effective earned value. For the hypothesis made earlier that for the tasks performed out of sequence rework is 50 percent, the equation for the effective earned value becomes:

$$EV(e) = [(1 + 0.5 * P) / (1 + 0.5)] * EV = [(P + 2) / 3] * EV \quad (10)$$

6. Applying effective earned value (EV(e))

The effective earned value affects the values of cost and schedule performance efficiencies, subsequently used for predicting project outcomes. The *effective* cost performance index, CPI(e), which describes the efficiency toward achieving completion of the project is:

$$CPI(e) = EV(e) / AC \quad (11)$$

Proceeding, the formula for calculating an *effective* independent estimate at completion, IEAC(e), is created by replacing CPI with CPI(e) in the familiar IEAC equation:

$$IEAC(e) = BAC / CPI(e) \quad (12)$$

In analyzing how this equation reacts over the duration of a project it is easily deduced that IEAC(e) will compute values which are equal to or larger than the values from IEAC = BAC / CPI. At project completion, IEAC(e) and IEAC will compute identical values, the actual final cost. We know from the extensive studies of CPI that IEAC describes the low bound for cost throughout the project's stable region. Thus, the prediction of final cost by IEAC(e) is consistent with the findings from the studies cited earlier in the section of the paper, *Behavior of the Cost Performance Index*.

The effective earned value also has an impact on schedule prediction. EV(e) is used to determine a corresponding *effective* earned schedule, ES(e). Because EV(e) is less than or equal to EV, ES(e) likewise will be less than or equal to ES. Analogously to cost, the *effective* time-based schedule performance index using effective earned schedule is:

$$SPI(te) = ES(e) / AT \quad (13)$$

And, similarly to the creation of IEAC(e) for prediction of final cost, the formula for prediction of final project duration [10] becomes *effective* by replacing SPI(t) with SPI(te):

$IEAC(te) = PD / SPI(te)$, where PD is the planned project duration. (14)

It is conjectured that the prediction of schedule duration using this formula is subject to similar conditions as there are for cost. Recall, CPI is considered to be stable once the project has reached 20 percent complete; therefore until CPI has achieved stability, outcome prediction is considered to be extremely unreliable. It is reasonable then to assume SPI(t) and the P-Factor will require some period of performance before they can be considered stable, as well. Without having similar statistical testing results to those cited earlier for CPI, using the assumption of stability at 20 percent complete is a rational starting point.

7. Project outcome prediction

To illustrate the application of the P-Factor, notional data is used. Refer to Figure 4, Graphs of CPI, CPI(e) & P-Factor (notional data) to observe the behavior of CPI. As discussed in the section, *Behavior of the Cost*

Performance Index, CPI tends to worsen as the project moves toward completion with the final CPI not more than 0.10 below its value when the project is 20 percent complete. Recall, this behavior is well known from several studies [2,3,4,5,6]. The CPI graph depicts the final value of CPI to be approximately 0.10 less than its value at 20 percent complete. Thus, the plot shows the maximum expected change for CPI.

Now observe the behavior of the P-Factor. Its value begins at 0.73 and increases until it reaches 1.0 at project completion. The P-Factor has an innate characteristic of increasing as the project moves toward completion. Thus, the use of the P-Factor to adjust the earned value to a lower amount causes the effective value of the cost performance index, CPI(e), to better forecast the final CPI value, and hence an improved prediction of final cost.

This effect is seen in the plot of CPI(e). Of course, the perfect compensation indicated is an unreasonable expectation. Nevertheless, the concept should be understood; the application of the P-Factor in conjunction with projected rework causes CPI(e) to be a better forecast of the final CPI throughout the stable period of performance for the project.

Before concluding, a few observations are made comparing the theory to known project behavior. From the definition of the P-Factor, its value indicates the portion of earned value accrued in congruence with the plan; i.e., the tasks which ought to be either completed or in work. Thus, for a project to drop 0.10 from its CPI value at 20 percent complete, our example tells us that approximately 30 percent of the project's task effort is performed not in accordance with the project plan. A project having 30 percent of its effort not following its plan is headed for disaster.

From the behavior of CPI and CPI(e) shown in figure 4 the predicted results for final cost is apparent. The values computed for IEAC(e) are consistently greater than the corresponding values for IEAC. Recall from the IEAC and CPI studies cited that the result from IEAC = BAC / CPI is a reasonable running estimate of the low value for final cost. Logically, it must follow that the more pessimistic estimate of final cost, IEAC(e), should be a closer estimate of the final cost.

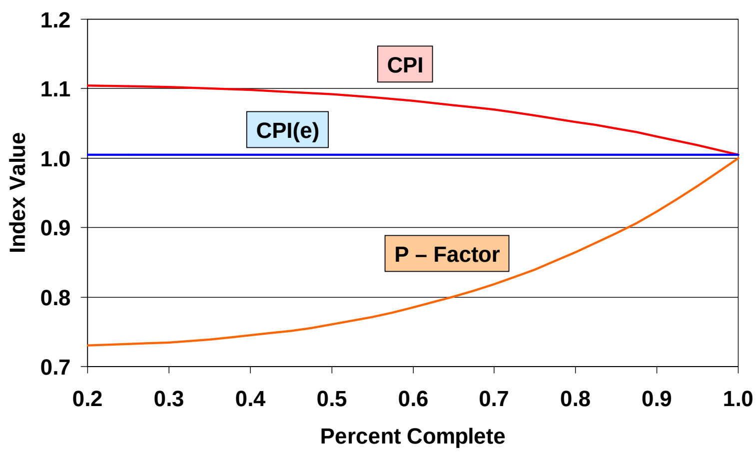

Figure 4. Graphs of CPI, CPI(e) & P - Factor (notional data)

The schedule duration estimate from the equation IEAC(t) = PD / SPI(t) has yet to be studied sufficiently as to its predictive validity. At this time however, we do know that it is a better predictor than any other method now employed. The other prediction methods have calculations with mathematical flaws which prevent their proper functioning [10].

From application to real data, I have observed the consistency of the predicted values for both IEAC(t) and IEAC(te). Just as for cost prediction, the schedule duration IEAC(te) is always longer than the corresponding IEAC(t). Until more study is completed, it remains conjecture that IEAC(te) is closer to the final project duration than is IEAC(t).

8. Summary

The premise put forth by this paper is that Earned Value Management (EVM) is connected to the schedule through the use of the Earned Schedule (ES) concept. The computed value of ES is used to identify the tasks of the plan that should be completed or in-work. Furthermore, the ES value identifies the portion completed for the in-work tasks. *This attribute of ES is independent of schedule performance efficiency.*

By comparing the actual task distribution of the earned value to the planned execution, differences can be observed. For those tasks where earned value (EV) lags the expectation, impediments or constraints are the likely cause. For tasks where EV exceeds expectation, the work is being performed without all of the task inputs satisfied; thus, rework can be expected at some future time. Both situations, task performance ahead and lagging with respect to the plan, cause costs to escalate and schedules to lengthen.

A measure was introduced to indicate the adherence to the project plan. The measure is the P-Factor, and is computed as the ratio of the EV corresponding to the plan divided by the total EV. This indicator is made possible through the application of the Earned Schedule (ES) concept, linking EV to the schedule.

The P-Factor in conjunction with rework is then used to form an adjustment factor. This factor adjusts the accrued EV to a lower amount, termed "effective earned value," and symbolically noted EV(e). The reduced EV is then used to calculate effective ES; i.e., ES(e). These effective values are, in turn, used to calculate effective cost and schedule performance efficiencies, CPI(e) and SPI(te), respectively. Finally, the independent estimates at completion for cost and schedule are computed using these efficiencies.

The analysis presented indicates the theory is in agreement with the several cited studies. *The P-Factor, derived from the application of Earned Schedule, provides the "bridge" connecting Earned Value Management to the project schedule.*

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