Schedule Adherence and Rework

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Abstract. When project performance is such that the product is delivered with expected functionality at the time and price agreed between the customer and supplier, it is deemed "successful." The rework, encumbering any project, has a measurable impact on whether a project can achieve success. The project manager (PM), who exercises control of the contributors to rework, can greatly enhance the prospect of delivering the product within its constraints. A significant portion of rework is caused by deviating from the project plan and its associated schedule. The measure of schedule adherence is derived from applying Earned Schedule (ES) to Earned Value Management (EVM) data. This paper first reviews the concept of schedule adherence and then develops an approach to understanding the cost impact from not adhering to the schedule. Finally, an index is proposed which provides information to assist project control and to forecast the cost associated with imperfect schedule adherence.

Background

An extension to EVM, ES was introduced in the March 2003 issue of The Measurable News [1]. The purpose of ES was to overcome the anomalous behavior of the EVM schedule performance indicators by providing reliable time-based indicators.[1] After ES was initially verified [2] and, subsequently, extended to forecasting project duration [3], it was shown to have further application.

One unique quality of the ES measure is that it facilitates identifying the specific Planned Value (PV) that should have been accomplished for the reported Earned Value (EV). This characteristic was first explained and examined in the article, "Connecting Earned Value to the Schedule," published in the Winter 2004 issue of The Measurable News [4]. Subsequently, this extended capability of ES was more fully elaborated in the April, 2008 CrossTalk article, "Schedule Adherence: a useful measure for project management" [5].

Because the task specific PV is identifiable, comparisons can be made to the task EV reported. The differences in PV and EV for each task are utilized to isolate problems occurring in the execution of the project. When the difference, EV − PV, is negative, there is a possibility of a constraint or impediment preventing task progress. This information is extremely useful. Having these tasks identified, allows the PM to focus on investigating and relieving problems that are causing workarounds. Minimizing the impact of constraints and impediments, in turn, minimizes the extent of workarounds, thus maximizing execution in agreement with the schedule. The more execution agreement there is between actual accomplishment and the schedule, the greater the performance efficiency becomes—for both cost and schedule.

Along with the negative differences previously discussed, there are positive differences identified for specific tasks. The positive differences expose areas where rework may occur.

There are many causes of rework:

- **Poor planning stemming from requirements misinterpretation, incorrect task sequencing, and poor estimation**
- **Defective work**
- **Poor requirements management**
- **Schedule compression during execution**
- **Over zealous quality assurance**

However, the rework identified when EV − PV is positive is none of the ones cited above. The rework for which we are concerned is solely caused by project execution not in the activity sequence prescribed by the schedule. Although out of sequence performance is only one of the six contributors to rework mentioned, it has a major impact. Out of sequence performance is pervasive in that it is not aligned with a single aspect or project event. Rather, it occurs dynamically and can involve any, and possibly all of the project team throughout the entire period of performance.

For readers who have some background in quality and process improvement activity, the discussion thus far may bring to mind the idea of process discipline. The lack of process discipline leads to the creation of defects and inefficient performance. As has been described thus far, ES provides a way to identify and measure process performance discipline.

Schedule Adherence

Figure 1 provides a visual for discussing further the ideas from the previous section. The darkened tasks to the right of the vertical ES line indicate performance resulting from impediments and constraints or poor process discipline. Frequently, they are executed without complete information. The performers of these tasks must necessarily anticipate the inputs expected from the incomplete preceding tasks; this consumes time and effort and has no associated earned value. Because the anticipated inputs are very likely misrepresentations of the future reality, the work accomplished (EV accrued) for these tasks usually contains significant amounts of rework. Complicating the problem, the rework created for a specific task will not be recognized for a period of time. The eventual rework will not be apparent until all of the inputs to the task are known or its output is recognized to be incompatible with the requirements of a subsequent task.

This conceptual discussion leads to the measurement of 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:

$$P = \sum EV_k / \sum PV_k$$

PV_k represents the planned value for a task associated with ES. The subscript "k" denotes the identity of the tasks from the schedule that comprise the planned accomplishment. The sum of all PV_k is equal to the EV accrued during time duration at which an EV measurement is reported (AT). EV_k is the earned value for the "k" tasks, limited by the value attributed to the planned tasks, PV_k. Consequently, the value of P, or P-Factor, represents the proportion of the EV accrued which exactly matches the planned schedule.

A characteristic of the P-Factor is that its value must be between zero and one; by definition, it cannot exceed one. A second characteristic is that P will exactly equal 1.0 at project completion. P equal to zero indicates that the project accomplishment thus far is not, at all, in accordance with the planned schedule. In opposition, P equal to one indicates perfect conformance.

When the value for P is much less than 1.0, indicating poor schedule adherence, the PM has a strong indication the project will have rework at some point in the future. Conversely, when the value of P is very close to 1.0, the PM can feel confident the schedule is being followed and that milestones and interim products are being accomplished in the proper sequence. The PM thus has an indicator derived from ES that further enhances the description of project performance portrayed by EVM alone.

Derivation of Rework

The diagram shown in Figure 2 is provided to aid the derivation for computing rework. To understand how P can be used beyond its qualitative application, let us refresh the fundamental relationships to this point:

1. EV accrued = $\sum EV_i$ @ AT = $\sum PV_k$ @ ES
   subscript "i" identifies tasks that have earned value

2. EV earned in accordance with the schedule:
   EV(p) = $\sum EV_k$ @ AT = $P \sum EV$ (see note 2)

3. EV earned not according to the schedule:
   EV(r) = EV − EV(p) = (1 − P) • EV

These relationships provide a basis for examining the impact of rework and are extremely important to the remainder of this section of the paper.

To begin, we know from the earlier discussion of the P-Factor that a portion of EV(r) is unusable and requires rework. If the unusable portion can be determined, then the quantity of rework is calculable. Progressing on, the rework and usable fractions of EV(r) are defined as follows:

Rework fraction: f(r) = EV(-r) / EV(r)
Usable fraction: f(p) = EV(+r) / EV(r)

where EV(r) = EV(-r) + EV(+r)
and   f(r) + f(p) = 1

Using the definitions, rework (R) can be computed from EV, P, and f(r):

R = EV(-r) = f(r) • EV(r) = f(r) • (1 − P) • EV

The quantities, EV and P, are obtainable from the reported status data. A method for determining f(r) is all that remains to have a calculation method for rework.

Logically, the project team's ability to correctly interpret the requirements for the work remaining increases as the project progresses toward completion. The end point conditions for this relationship are: f(r) = 1 when C = EV/BAC = 0 and f(r) = 0 when C = 1. Carrying this idea forward, the fraction of EV(r) fore-
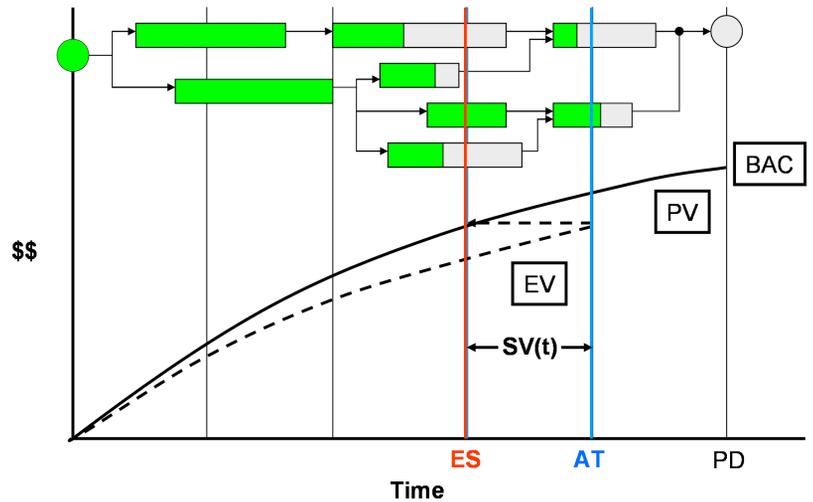

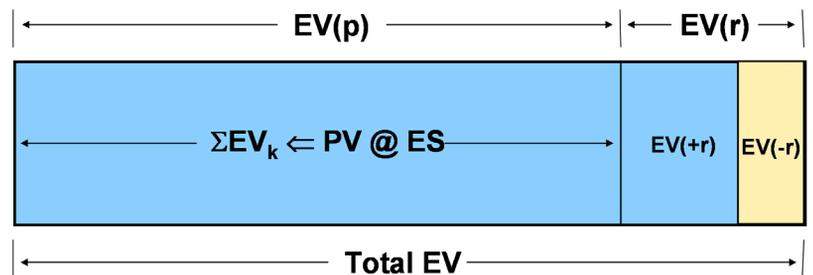Figure 1. Actual Versus Planned Performance

Figure 2. Rework Diagram

cast to require rework must then decrease as EV/BAC increases. It is further hypothesized that the rate of rework decrease for f(r) becomes larger and larger as the project nears completion.

The formula proposed which meets the conditions outlined is:

f(r) = 1 − C^n • e^(-m • (1 − C))

where C = fraction complete of project (EV/BAC)
e = natural number (base "e")
^ = signifies an exponent follows

The exponents, m and n, are used to adjust the shape of the f(r) curve. Presently, calculations of f(r) are recommended to be made using n = 1 and m = 0.5. These values for the exponents yield a nearly linear decreasing value for f(r) as fraction complete increases. It has been speculated that the behavior of f(r) should be more exaggerated; for example, a graph of f(r) versus EV/BAC having the general appearance of the perimeter of a circle in the first quadrant. The mathematical equation for f(r) is capable of generating this behavior as well as others. Further research is needed regarding the behavior of f(r) to substantiate use of the equation above and the recommended values for m and n.

Inserting m = 0.5 and n = 1 into the general equation for f(r), the equation for rework can be stated:

R = (1 − C • e^(-0.5 • (1 − C))) • (1 − P) • EV

Thus, in its final form, rework is a function of the EV accrued, the degree of schedule adherence (P), and the fraction complete (C or EV/BAC).

Computation Methods

The equation for R computes the amount of rework forecast to occur from the present status point to project completion due to the current measure of schedule adherence. It is an intriguing computation, but it is not a useful indicator for PMs. Recall that P increases as the project progresses and concludes at the value of 1.0 at completion, regardless of efforts by managers or workers to cause improvement. Thus, the computed value of R from one status point to the next cannot provide trend information concerning improvement and neither can it lead to a forecast of the total amount of rework caused by lack of schedule adherence.

At this point R appears to be a useless calculation. However, by recognizing that the rework value computed is distributed over the remainder of the project, it can be transformed easily to a useful indicator. It makes sense to normalize R to the work remaining; i.e., the project budget, less reserve, minus the planned value of work accomplished.[3]

The value of R divided by work remaining is the definition for the Schedule Adherence Index (SAI):

$$SAI = R / (BAC - EV)$$

The indicator is useful for detecting trends and is, therefore, an indicator by which a manager can gauge his or her actions taken. The interpretation of the indicator is straightforward. When SAI values increase with each successive status evaluation, Schedule Adherence (SA) is worsening. Conversely, when SAI decreases with time, SA is improving.

Having SAI provides the ability for calculating the rework created within a performance period along with the cumulative effects from imperfect SA. Additionally, it provides computational capability for forecasting the total rework from the lack of schedule adherence. Rework within a performance period is computed through a trapezoidal approximation technique, illustrated in Figure 3.

For the graphical depiction, the area computed for each period is in terms of cost of rework per unit of budget. Thus, to obtain the rework cost for any period, the computed area is multiplied by Budget at Completion (BAC):

$$Rp(n) = BAC \cdot [\frac{1}{2} \cdot (SAI_n + SAI_{n-1}) \cdot (C_n - C_{n-1})]$$

where n = the performance period of interest

The first and last index values, SAI_0 and SAI_N, are equal to 0.0.

With the methodology established for computing the cost of rework for any period, it becomes a trivial matter to calculate the cumulative cost. The cumulative accrual of rework (R_{cum}) generated from imperfect SA is the summation of the periodic values: $R_{cum} = \sum R_p(n)$.

The method for forecasting the total rework caused by performance deviations from the schedule is very similar to the formula used for forecasting final cost from EVM.[4] The formula for the Total Rework Forecast (R_{tot}) is

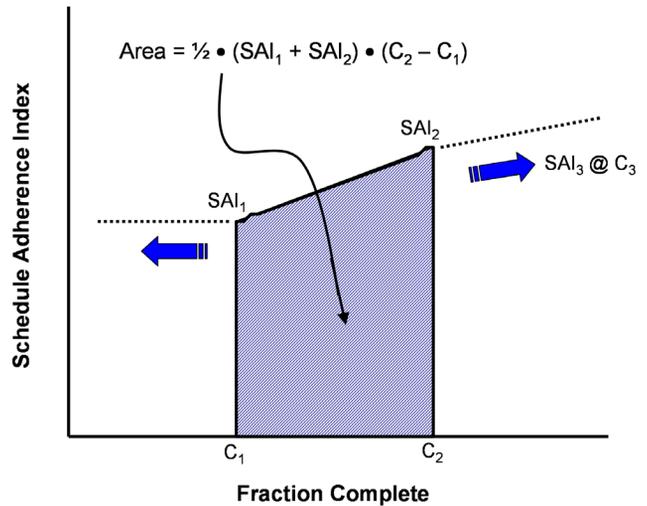Area = ½ • (SAI₁ + SAI₂) • (C₂ − C₁) ... (figure labels)

Figure 3. Area Calculation Method

$$R_{tot} = R_{cum} + SAI \cdot (BAC - EV)$$

This formula makes possible, for each project status point, the computation of total rework forecast from imperfect schedule execution.

To clarify what R_{tot} represents, it is the forecast of actual cost for rework from imperfect execution of the schedule. From experience, rework cost is closely aligned with planned cost. It, generally, does not experience the execution inefficiencies incurred in the initial performance of the tasks.

Notional Data Example

The data provided in Table 1 is utilized to demonstrate the theory and calculation methods described in the previous sections of this paper. For our example, the schedule adherence shown by the values of P are very poor. P does not exceed 0.8 until status point 9, where the project is nearly 85% complete. Normally, P-Factor values are expected to be greater than 0.8 before 20% complete. Because the adherence to schedule is poor, we should expect rework to be large with respect to BAC.

The computed values for SAI and forecast rework are tabulated in Table 2. As observed, the value of SAI increases until the project is approximately 60% complete and then improves as the project moves toward completion. As discussed previously, the value of SAI for the final status period (11) is shown equal to 0.0.

The values for the rework forecast are observed to rapidly increase until the project achieves 30% complete. From that point, the values increase at a slower rate until the peak value of $60 is reached at 61% complete. Afterward the SAI values improve and the rework forecast decreases and concludes at $46. To a large degree the rework forecast is reasonably stable from 30% complete until completion.

Possibly a clearer understanding of the computed results can be obtained from viewing Figure 4. SAI is observed to be rapidly increasing from the beginning, indicating schedule adherence is worsening. Then, once the project has progressed past 60% complete, SAI dramatically improves. The forecast cost of rework, due to imperfect schedule adherence, likewise rapidly increases from a value of $13 at the first status point to the maximum value of $60. Although SAI

greatly improves after its peak value, it is seen that the rework forecast improves only marginally. As the project moves toward completion, there is less and less of the project remaining upon which the SA improvements can have impact. Thus, the rework forecast is affected, but not to the extent of the change in SAI.

Real Data Example

The data in Table 3 is actual performance data from an in-work project, beginning at 22% through 84% complete. The BAC for the project is $2,488,202. As shown, the P-Factor is a high value initially, 0.930, and increases to 0.995 by 75% complete, and remains fairly constant for the status points that follow. The schedule adherence for this project is incredibly good. Not only is SA good, Cost Performance Index (CPI) and Schedule Performance Index-time (SPI(t)) are very good as well, 1.05 and 0.98, respectively.

Although only a single set of correlated data, the fact that all of the indexes have relatively high values demonstrates the conjecture that when SA is good, cost and schedule performance are maximized. If the conjecture is true, then the SA index is an important management indicator. The implication is the appropriate use of SAI as an additional management tool will increase the probability of having a successful project.

Table 4 contains the computed results for SAI and forecast of rework cost from imperfect schedule adherence. As expected for such high values of P, SAI is extremely low. The highest value is 0.028, while the lowest is 0.005. To have a sense of the distinction between poor SAI values and good ones, compare the values provided in Tables 2 and 4. The poor values of Table 2 are as much as 89 times greater than those shown in Table 4.

The average of the forecast rework cost for the real data example is slightly less than $42,000 or only 1.7% of BAC, a remarkably low number. The estimate of the standard deviation from the forecast values is $8,300. Utilizing the standard deviation, we can say it is extremely unlikely that the actual final rework cost will be greater than $67,000; i.e., $42,000 plus 3 standard deviations (3 x $8,300 = $24,900).

The graphs of SAI and the rework cost forecast are shown in Figure 5. The two plots are shaped similarly, both having negative trends. The graphs clearly show schedule adherence improving after the project is 40% complete. Assuming the improving trend continues, the rework cost at completion will be less than $40,000 or only 1.6% of BAC.

Summary

From the time of the introduction of the schedule adherence measure, P, there has been a desire to have the capability for understanding its implications; i.e., the cost of the induced rework. It was long thought that the complexity and difficulty of performing the necessary calculations would far outweigh the benefit from having the resultant information. However, as has been shown in this paper, the calculations are not that encumbering. Having the values for the P-Factor, the cost of rework can be forecast with relative ease. And thus, the importance of executing schedule, as intended, can be quantified by cost; i.e., the amount of waste caused by imperfect schedule performance.

Status Point	1	2	3	4	5	6
EV	$14	$37	$58	$82	$97	$113
P	0.082	0.208	0.247	0.337	0.371	0.431
Status Point	7	8	9	10	11	
EV	$125	$137	$157	$177	$185	
P	0.520	0.650	0.822	0.955	1.000	

Table 1. Notional Data

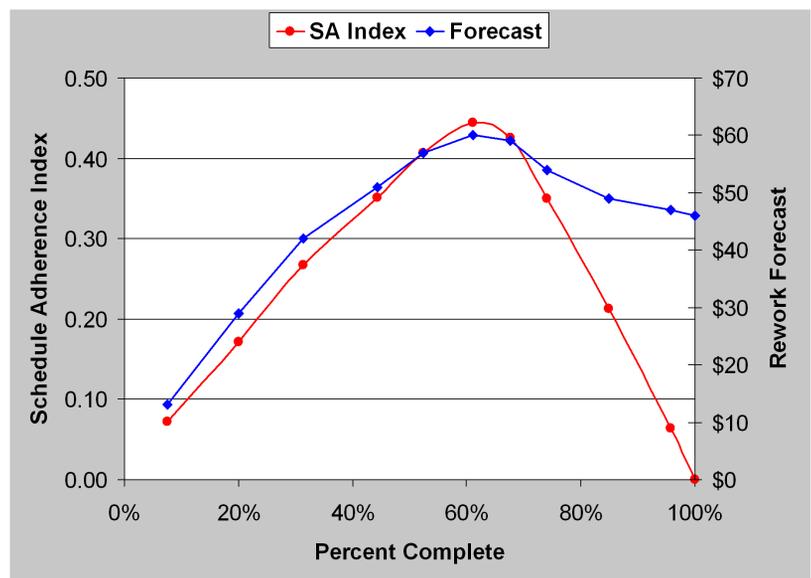| Status Point	1	2	3	4	5	6
Percent Complete	7.6%	20.0%	31.4%	44.3%	52.4%	61.1%
SA Index	0.072	0.171	0.267	0.351	0.407	0.444
Rework Forecast	$13	$29	$42	$51	$57	$60
Status Point	7	8	9	10	11	
Percent Complete	67.6%	74.1%	84.9%	95.7%	100.0%	
SA Index	0.425	0.350	0.213	0.064	0.000	
Rework Forecast	$59	$54	$49	$47	$46	

Table 2. Computed Values (Notional Data)

Figure 4. Rework Forecast (Notional Data)

Status Point	1	2	3	4	5
EV	$549,707	$668,776	$784,508	$881,288	$986,529
P	0.930	0.915	0.963	0.962	0.939
Status Point	6	7	8	9	10
EV	$1,299,880	$1,422,033	$1,526,842	$1,617,976	$1,716,130
P	0.957	0.975	0.970	0.975	0.984
Status Point	11	12	13	14	
EV	$1,826,991	$1,930,651	$2,015,852	$2,088,967	
P	0.994	0.995	0.996	0.993	

Table 3. Real Data

Status Point	1	2	3	4	5
Percent Complete	22.1%	26.9%	31.5%	35.4%	39.6%
SA Index	0.017	0.026	0.013	0.015	0.028
Rework Forecast	$37,483	$53,697	$31,945	$35,577	$55,671
Status Point	6	7	8	9	10
Percent Complete	52.2%	57.2%	61.4%	65.0%	69.0%
SA Index	0.027	0.018	0.023	0.021	0.014
Rework Forecast	$54,401	$43,519	$49,221	$46,812	$41,443
Status Point	11	12	13	14	
Percent Complete	73.4%	77.6%	81.0%	84.0%	
SA Index	0.006	0.005	0.005	0.008	
Rework Forecast	$35,349	$34,821	$34,754	$36,377	

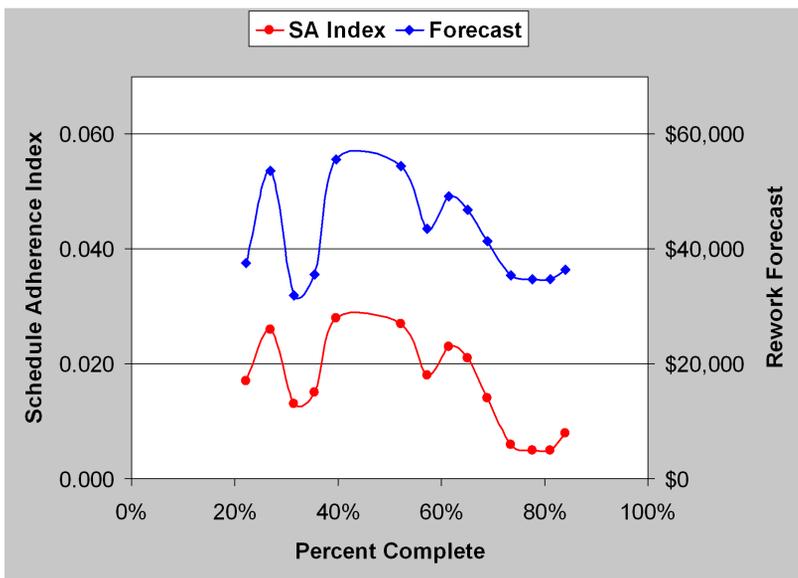Table 4. Computed Results (Real Data)

Figure 5. Rework Forecast (Real Data)

In this paper, the introduction of the SAI is shown to be integral to the forecast of rework cost. The approximation method for making the forecast calculation is diagrammed and discussed. The calculation methods are applied to both notional and real data to illustrate their application and simplicity.

The additional capability afforded by ES, to identify the impact of rework from poor schedule adherence, provides PMs an additional and valuable tool for guiding their project to successful completion.

Final Comment

To encourage application and uptake of the capability discussed in this paper, a calculator is made available for download from the calculators page of the earned schedule website, <http://www.earnedschedule.com/Calculator.shtml>. The calculator is titled, "SA Index and Rework Calculator." The calculator includes instructions and example data for trial use. ❖

ABOUT THE AUTHOR

Walt Lipke retired in 2005 as deputy chief of the Software Division at Tinker Air Force Base. He has more than 35 years of experience in the development, maintenance, and management of software for automated testing of avionics. During his tenure, the division achieved several software process improvement milestones, including the coveted SEI/IEEE award for Software Process Achievement.

Mr. Lipke has published several articles and presented at conferences, internationally, on the benefits of software process improvement and the application of earned value management and statistical methods to software projects. He is the creator of the technique Earned Schedule, which extracts schedule information from earned value data. Mr. Lipke is a graduate of the DoD course for Program Managers. He is a professional engineer with a master's degree in physics, and is a member of the physics honor society, Sigma Pi Sigma.

Lipke achieved distinguished academic honors with the selection to Phi Kappa Phi. During 2007 Mr. Lipke received the PMI Metrics Specific Interest Group Scholar Award. Also in 2007, he received the PMI Eric Jenett Award for Project Management Excellence for his leadership role and contribution to project management resulting from his creation of the Earned Schedule method. Mr. Lipke was selected for the 2010 Who's Who in the World.

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NOTES

1. The schedule performance indicators derived from Earned Schedule are Schedule Variance-time (SV(t) = ES - AT) and Schedule Performance Index-time (SPI(t) = ES / AT), where AT is the time duration at which an EV measurement is reported.
2. Recall that EVk is limited by the value of PVk.
3. In the terminology of EVM, the work remaining = BAC – EV, where BAC is Budget at Completion [6]
4. Final cost (IEAC) = AC + (BAC – EV) / CPI, where IEAC = Independent Estimate at Completion, AC = Actual Cost, and CPI = Cost Performance Index.