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Earned Schedule
Schedule performance analysis from EVM measures

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Abstract

Earned Value Management (EVM) is a wonderful management system, integrating, in a very intriguing way, cost …schedule …and technical performance. It is a system, however, that causes difficulty to those just being introduced to its concepts. EVM measures schedule performance not in units of time, but rather in cost, i.e. dollars. After overcoming this mental obstacle, we later discover another quirk of EVM: at the completion of a project which is behind schedule, Schedule Variance (SV) is equal to zero, and the Schedule Performance Index (SPI) equals unity. We know the project completed late, yet the indicator values say the project has had …<u>perfect schedule performance</u>!! A senior executive receiving the project performance report, minimally knowledgeable of EVM, cannot understand why he has an angry customer screaming, "Your product delivery is late!" This paper discusses the dilemma with the EVM schedule indicators, SV and SPI. A method for resolving the problem is presented in the paper. It is shown that the result from the method is schedule indicators having the same behavior as those for cost.

Foreword

This paper is a re-publication of my seminal article on Earned Schedule (ES) [Lipke, 2003]. Although the knowledge and use of ES has grown immensely and spread globally over the last eight years, the method remains unknown to many. The article is intended to raise the curiosity and interest of those who are unaware of the method and further expand the uptake of ES.

From 2003 until the present much has happened. For those applying ES, the method is broadly considered to be a significant advancement to the practice of EVM. ES has propagated across the world, including the USA, Australia, United Kingdom, Belgium, Spain, Canada, India, and other countries, as well. It is being used across all industries

[1] *Second Editions are previously published papers that have renewed or continued relevance in today's project management professional world. Original publication acknowledged; authors retain copyright.*

applying EVM for all sizes of projects. Furthermore, the method is being used in research, instructed in some universities, and is included in recent project management texts and the newer EVM analysis tools. Presently an ES appendix is being prepared for inclusion in the PMI® *Practice Standard for Earned Value Management*.

The measure of ES has provided analysis and forecasting capability to those using EVM, until now not believed possible. Parallel to forecasting final cost using EVM measures, ES facilitates a simple calculation for the forecasting of project completion dates. Additionally, another measure has been derived from ES, "Schedule Adherence." This measure, in turn, has provided the capability to perform detailed analysis, yielding identification of process constraints and impediments and specific tasks having the likelihood of future rework. Additionally, calculation methods have been developed recently for determining the value of the out of sequence work and the rework cost caused by imperfect schedule adherence. These advancements are not addressed in this article; however literature is freely available for your study and exploration at the Earned Schedule website, www.earnedschedule.com.

As you will see in reading the article, the concept of ES is very straight forward. It is not difficult to grasp. Furthermore, if you are presently using EVM in your approach to project management, there is almost insignificant effort required to add and utilize the capabilities offered by ES. I hope with this preface that you are inspired to read on.

Introduction

Within the Software Division (SD) at Tinker AFB, an organization I once managed, Earned Value Management (EVM) has been applied for several years. It has proven to be a tremendous aid to project planning, tracking, and decision-making. And, the reporting methods of EVM serve as a good tool for communicating with management and customers, as well. Over the years, the SD has evolved the application of EVM. Statistical techniques are used to predict project outcomes, and historical data is used for new project planning.

To confidently apply EVM data for outcome prediction and project planning, the numbers must reflect the real performance of the project. It is known that the schedule indicators of EVM fail to provide good information, nominally, over the final third of the project; they absolutely breakdown if the project is executing past its planned completion date. To overcome this deficiency, the SD has been applying the concept and methods of "Earned Schedule" for several years. The remainder of this paper discusses the concept, its associated schedule indicators, and their behavior.

Earned Value Basics

Before proceeding to the detailed portions of this paper, let's review the basics of Earned Value. Figure 1 illustrates three characteristic S-curves of cost versus time. The curves are labeled, PV, EV, and AC. The PV curve depicts the planned value, i.e. expected cost versus time, to project completion. The AC curve is a graph of actual cost accrual with time. Lastly, the EV curve portrays the "earned value." Fundamentally, as tasks are completed the project accrues the cost planned for those tasks as earned value.

The Earned Value Management (EVM) indicators are derived from the three S-curves. As shown on Figure 1, Schedule Variance (SV) is the computed cost difference, EV - PV, while the Cost Variance (CV) is the difference, EV - AC. The Cost and Schedule Performance Indexes, CPI and SPI, respectively, are ratios. SPI is computed from the ratio, EV/PV, while CPI equals EV/AC. Both sets of indicators are computed at periodic status points, usually monthly. The reference for this paper, Quentin Fleming's book, *Cost/Schedule Control /Systems Criteria, The Management Guide to C/SCSC,* provides a much more in depth discussion of EVM and its management indicators [Fleming, 1988].

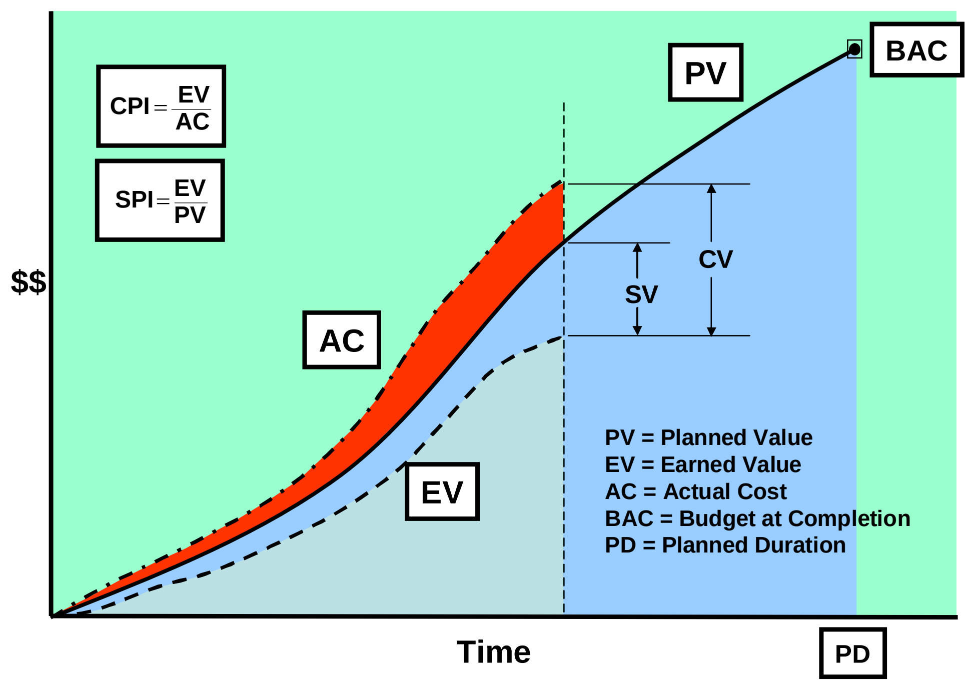
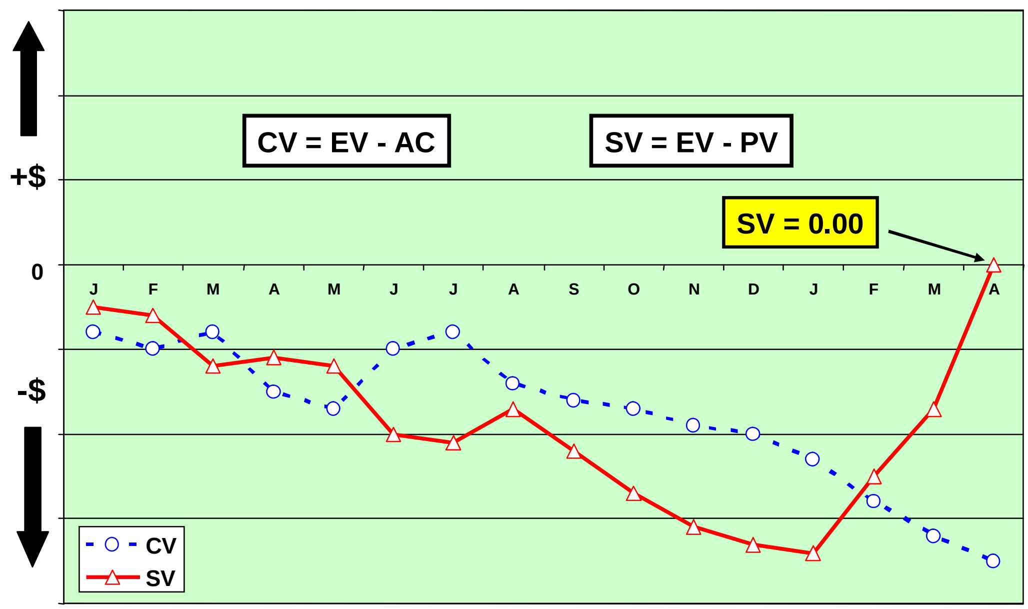


Figure 1. Earned Value Basics

The Problem

To begin, reference Figure 2, Cost and Schedule Variances, and Figure 3, Cost and Schedule Performance Indexes. Note how the cost indicators (CV, CPI) behave, and then view the indicators for schedule (SV, SPI). The cost indicators behave differently from those for schedule. The cost indicators appear to establish a trend with some variation. Similarly, the schedule indicators initially appear to establish a trend, but eventually begin moving toward their end result, zero variance and an index value equal to unity. This quirky behavior of SV and SPI occurs without fail for every project finishing late ….no matter how late. The behavior of the schedule indicators is especially bothersome to project managers attempting to present their project indicators to EVM semi-literate executives. How do they explain that the project is estimated to deliver the product late (possibly, it's already past due), when the schedule trend indicates the project is recovering and appears headed for an on-time completion? It's a tough sell to claim the indicators mean anything, and furthermore they could have a more sinister interpretation …*the boss thinks the project manager is trying to pull a "fast one."*

In the long run, this anomalous behavior of the schedule indicators with its accompanying misinterpretations and misunderstandings weakens the initiative to broaden the acceptance and application of EVM.



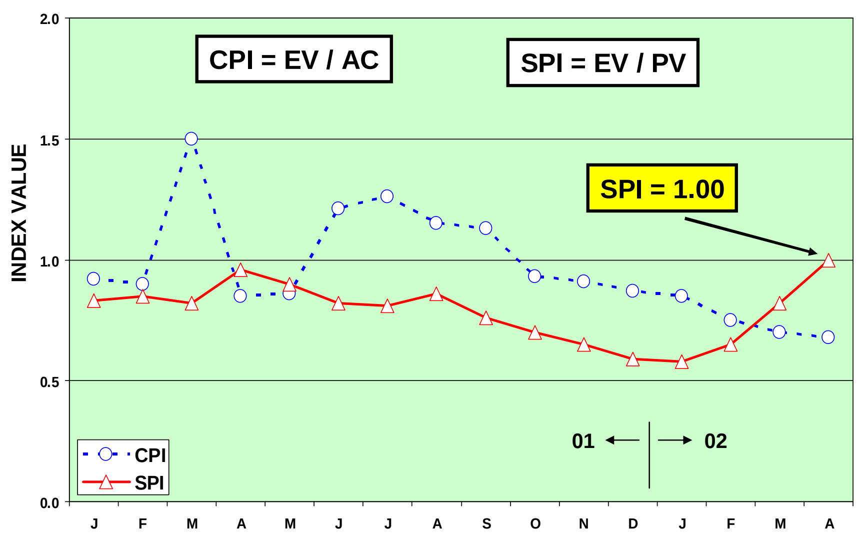
Note: Project completion was scheduled for Jan 02, but completed Apr 03.

Figure 2. Cost and Schedule Variances

Certainly the creators of EVM in the mid-1960s didn't intentionally create a management system, which would label project managers as liars. Rather, EVM was created to better understand and control project performance, both cost and schedule. Believing this, then ….*Why does this "quirk" exist for the schedule indicators?* The question is likely unanswerable, only the management system's creators could provide this background. The best I can do is to describe the cause of the strange behavior.

To begin this discussion, note how cost is referenced versus schedule. The cost indicators are referenced to actual costs (AC), whereas the schedule indicators are referenced to the performance measurement baseline (PMB). It is this reference to PV, which causes the problem for the schedule indicators. The end-point of the PMB is the planned cost for the project, Budget at Completion (BAC). The end-point for the earned value (EV) is, likewise, BAC. Thus, as the EV approaches project completion, it converges to the planned cost. In the case of a late project, PV equals BAC, while EV incrementally achieves the value. From this explanation, you should now easily understand the behavior of the schedule indicators shown in Figures 2 and 3. Schedule Variance must converge to 0.0 at project completion, while the Schedule Performance Index concludes at 1.0.

The irregular behavior of the schedule indicators causes additional problems for project managers. At some point it becomes obvious when the SV and SPI indicators have lost their management value. But, there is a preceding gray area, when the manager cannot be sure of whether or not he should believe the indicator and subsequently react to it. From this time of uncertainty until project completion, the manager cannot rely on the schedule indicators portion of EVM.



Note: Project completion was scheduled for Jan 02, but completed Apr 03.

Figure 3. Cost and Schedule Performance Indexes

At this point I am going to inject some personal opinion. It is my observation, most project managers using EVM pay much more attention to cost than they do schedule. My belief is the cause of this focus on cost is, in large part, due to the unreliability of the EVM schedule indicators. The focus on cost may also be caused by the fact that schedule measurement is made using cost amounts. So, implicitly the impression is conveyed that if cost is managed, schedule will follow. As we all know, there is correlation between cost and schedule, but it is not a defined mathematical relationship. Therefore, the project's schedule performance cannot be taken for granted; it should be managed, too.

The Solution

In thinking about how to resolve the problem with the EVM schedule indicators, SV and SPI, the idea of simply averaging the individual monthly values was considered. However, it was quickly realized that the averaging method still didn't resolve the issue of when the indicators become questionable, and furthermore it introduced another problem. The average of the monthly values of SPI becomes indeterminate for projects completing later than planned; the value of the divisor becomes 0.0 upon reaching the planned completion point for the schedule because PV has reached its end-point value, BAC, and does not change thereafter. Recognizing this additional complication, the idea of simply averaging SPI or SV monthly data was quickly discarded as a potential solution.

The second approach was to create the concept of "Earned Schedule." The idea of Earned Schedule is analogous to Earned Value. However, instead of using cost for measuring schedule performance, we would use time. Earned Schedule is determined by comparing the cumulative EV earned to the performance baseline. The time associated with EV, i.e. Earned Schedule, is found from the PV S-curve. This concept of projecting EV onto PV is not truly new. It is illustrated in many books dealing with EVM (including Mr. Fleming's book [Fleming, 1988]). The significance of using the Earned Schedule concept is that the associated schedule indicators behave appropriately throughout the entire period of project performance.

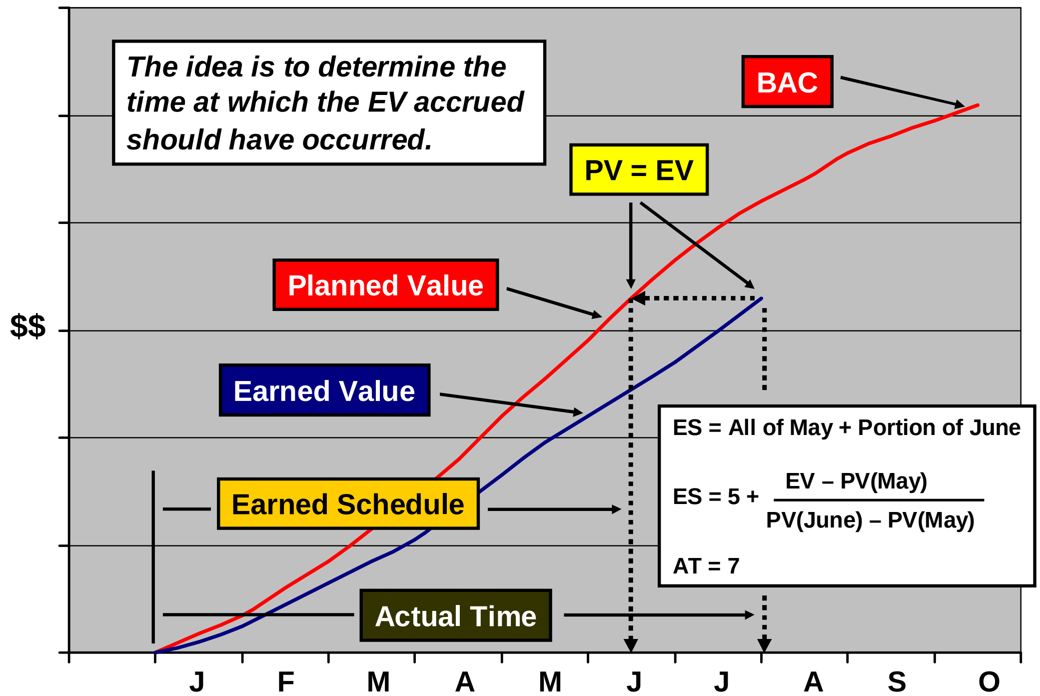


Figure 4. Earned Schedule Concept

More explicitly, Earned Schedule (ES) is computed as illustrated by Figure 4. The cumulative value of ES is found by using EV to identify in which time increment of PV the cost value occurs. The value of ES then is equal to the cumulative time to the beginning of that increment (e.g., months) plus a fraction of it. The fractional amount is equal to the portion of EV extending into the incomplete time increment divided by the total PV planned for that same time period.

To further explain, the ES computation process has two components:

(1) The number of time periods (C) of the PMB for which EV ≥ PV
(2) The fraction (I) of the C+1 period of the PMB

The value of period C is easily determined by counting the number of time increments of the PMB that satisfy the condition, EV ≥ PV. The computation of I is not so simple, but neither is it overly complex. The value of I is calculated by employing a linear interpolation method for the C+1 period of the PMB. The amount of EV extending into the C+1 period is equal to the difference EV minus PV_C, where PV_C is determined from the PMB value associated with period C. The periodic amount of PV for period C+1 is the difference PV_{C+1} minus PV_C. The fraction I is calculated from the quotient of these two values as follows:

$$I = (EV - PV_C) / (PV_{C+1} - PV_C)$$

When determined, the two values (C and I) are summed to become the value of ES; i.e., ES = C + I, where the units are time periods, commonly months or weeks.

Using ES, indicators can be formed which behave appropriately and analogously to the cost indicators:

Schedule Variance: SV(t) = ES – AT

Schedule Performance Index: SPI(t) = ES / AT

where AT is the actual time

The Schedule Variance, SV(t), is positive when the ES exceeds AT, and, of course, is negative when it lags. The Schedule Performance Index, SPI(t), is greater than 1.0 when ES exceeds AT, and is less than 1.0 when ES is less than AT. These proposed indicators are completely analogous to the EVM cost indicators, CV and CPI. The proposed schedule indicators are referenced to "actuals," just as are the EVM cost indicators.

Referring again to Figure 4, the performance portrayed is of a project having schedule performance lagging its plan. We'll use this figure as an example of the previous narrative to assist with understanding the ES calculation. Viewing the figure, the vertical dashed line from the point on the PMB where PV = EV intersects the time axis at a point occurring some time in the month of June.

The inset of the figure shows the calculation of ES and the value for AT. The time period at which the EV accrued is reported is the end of July, AT = 7. The whole number component of ES, i.e., C, is associated with the PV at the end of May or month 5.

The interpolated portion of ES, I, is spelled out in the insert of the figure:

I = [EV – PV(May)] / [PV(June) – PV(May)]

EV is larger than the PV value for May, but smaller than the PV value for June. Thus, the interpolation is made for June.

Let us now assign some values and make the calculation: EV = $100, PV(May) = $90, PV(June) = $110. Using the equation for I, we have:

I = [$100 – $90] / [$110 – $90] = 0.5 months

Notice that the PV planned for June execution is $110 minus $90, or $20. With C and I computed, ES is determined:

ES = 5 + 0.5 = 5.5 months

Using ES and AT, the time-based values for schedule variance and schedule performance index can be calculated:

SV(t) = ES – AT = 5.5 – 7 = -1.5 months
SPI(t) = ES / AT = 5.5 / 7 = 0.79

Thus, the indicators provide management information concerning the performance pictured in Figure 4. The project is behind schedule by one and one-half months and the planned schedule is being completed at the rate of 0.79 months for each month of execution.

Application

To further demonstrate the concept of Earned Schedule, notional data have been created for PV and EV. The data, along with the calculated results for ES, SV and SPI are tabulated in Table 1, Early Project Finish, and Table 2, Late Project Finish.

Before analyzing the data from the two Tables, we'll perform a few example calculations. Using the data from Table 2, we'll calculate the ES for August:

EV–August = $1900

PV–July = $1805

PV–August = $2135

The value of EV–August is greater than PV–July. Thus, ES is into the 8th month of the project baseline. Therefore,

ES = 7 + (1900 – 1805) / (2135 –1805)

= 7.288 months

As you can see, the calculation of ES is not at all difficult. The more complex component, I, is a simple linear interpolation of the amount of time duration to credit for the month partially completed.

With the computed ES value for August, we can calculate SV and SPI using the equations introduced earlier:

SV(t) = ES – AT	SPI(t) = ES / AT
= 7.288 – 8	= 7.288 / 8
= -0.712 months	= 0.911

The interpretation of the indicators is very easily understood. The schedule variance indicates the project lags its expected performance by 0.722 months. The schedule performance index tells us that the project is progressing at the rate of .911 planned months for each month of actual time.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PV	105	200	515	845	1175	1475	1805	2135	2435	2665	2760	2823
EV	115	220	530	870	1215	1525	1860	2190	2500	2740	2823	------
SV($)	10	20	15	25	40	50	55	55	65	75	63	------
SPI($)	1.095	1.100	1.029	1.030	1.034	1.034	1.030	1.026	1.027	1.028	1.023	------
Month Count	1	2	3	4	5	6	7	8	9	10	11	12
ES(mo)	1.105	2.063	3.045	4.076	5.133	6.152	7.167	8.183	9.283	10.789	12.000	------
SV(t)	0.105	0.063	0.045	0.076	0.133	0.152	0.167	0.183	0.283	0.789	1.000	------
SPI(t)	1.105	1.032	1.015	1.019	1.027	1.025	1.024	1.023	1.031	1.079	1.091	------

Table 1. Notional Data – Early Finish

	Year 01												Year 02		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
PV	105	200	515	845	1175	1475	1805	2135	2435	2665	2760	2823	------	------	------
EV	95	180	470	770	1065	1315	1610	1900	2150	2275	2425	2555	2695	2770	2823
SV($)	-10	-20	-45	-75	-110	-160	-195	-235	-285	-390	-335	-268	-128	-53	0
SPI($)	0.905	0.900	0.913	0.911	0.906	0.892	0.892	0.890	0.883	0.854	0.879	0.905	0.955	0.981	1.000
Month Count	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ES(mo)	0.905	1.789	2.857	3.773	4.667	5.467	6.409	7.288	8.050	8.467	8.967	9.522	10.316	11.159	12.000
SV(t)	-0.095	-0.211	-0.143	-0.227	-0.333	-0.533	-0.591	-0.712	-0.950	-1.533	-2.033	-2.478	-2.684	-2.841	-3.000
SPI(t)	0.905	0.895	0.952	0.943	0.933	0.911	0.916	0.911	0.894	0.847	0.815	0.793	0.794	0.797	0.800

Table 2. Notional Data – Late Finish

If a project manager desires to analyze the monthly trends of SV(t) and SPI(t), they can be easily derived from the cumulative values. The monthly values of ES and AT are computed from the differences in their respective cumulative values for successive months. Thus, the monthly formulas for SV and SPI are:

$$SV(mo)_n = [ES(cum)_n – ES(cum)_{n-1}] – [AT(cum)_n – AT(cum)_{n-1}]$$

$$SPI(mo)_n = [ES(cum)_n – ES(cum)_{n-1}] / [AT(cum)_n – AT(cum)_{n-1}]$$

where the subscript n is the number of the month from the beginning of the project.

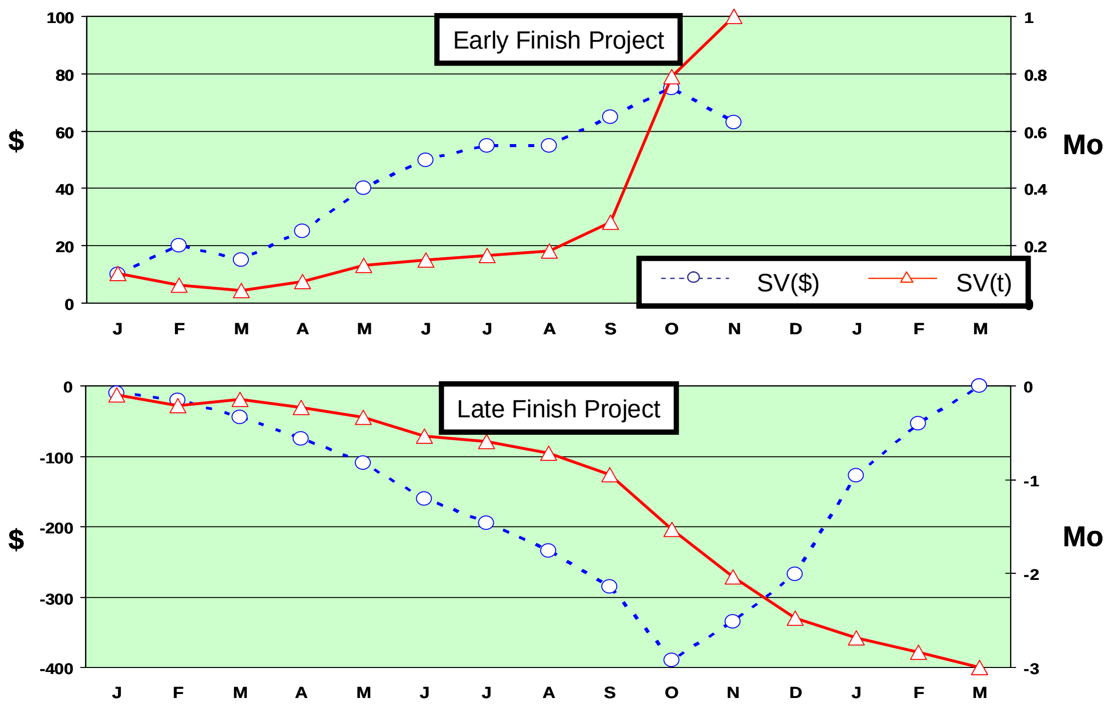


Figure 5. Notional Data – SV($) & SV(t) Comparison

For most of the project, the difference in successive values of AT(cum) is 1.0. If the actual time at the beginning or end of a project does not include an entire month, the value of AT for that month is calculated using the fraction of the month worked. The fraction is the number of planned days worked divided by the normal workdays in the month. To clarify this computation, let's assume we have a project, which began on February 18, President's Day, a USA Federal holiday. Thus, the first day is not a planned workday.

There are 8 planned workdays from February 18 through February 28. February has 19 normal workdays. Therefore, the actual time for the beginning month of our example is:

AT(Feb) = 8 / 19

= 0.421 months

For Tables 1 and 2, the performance measurement baseline begins on January 1 and concludes on December 31. Thus, each month within both tables is a full month; there are not fractions of months to calculate at the beginning or end of either the early or the late project.

The computed values of SV for both the early and late projects are shown graphically in Figure 5. The EV method of portraying SV using cost differences (shown as SV($)) correlates fairly well trend-wise with the ES method (shown as SV(t)) until September. SV(t) begins increasing from the September value, while SV($) shows an up and down change. We know the project finished one month early. Using the methods described for ES, we calculated SV(t) to be one month early; the computed value is equal to the known project performance. The EVM method of computing SV, as discussed earlier, yields a result that is difficult to comprehend; it's not in units of time.

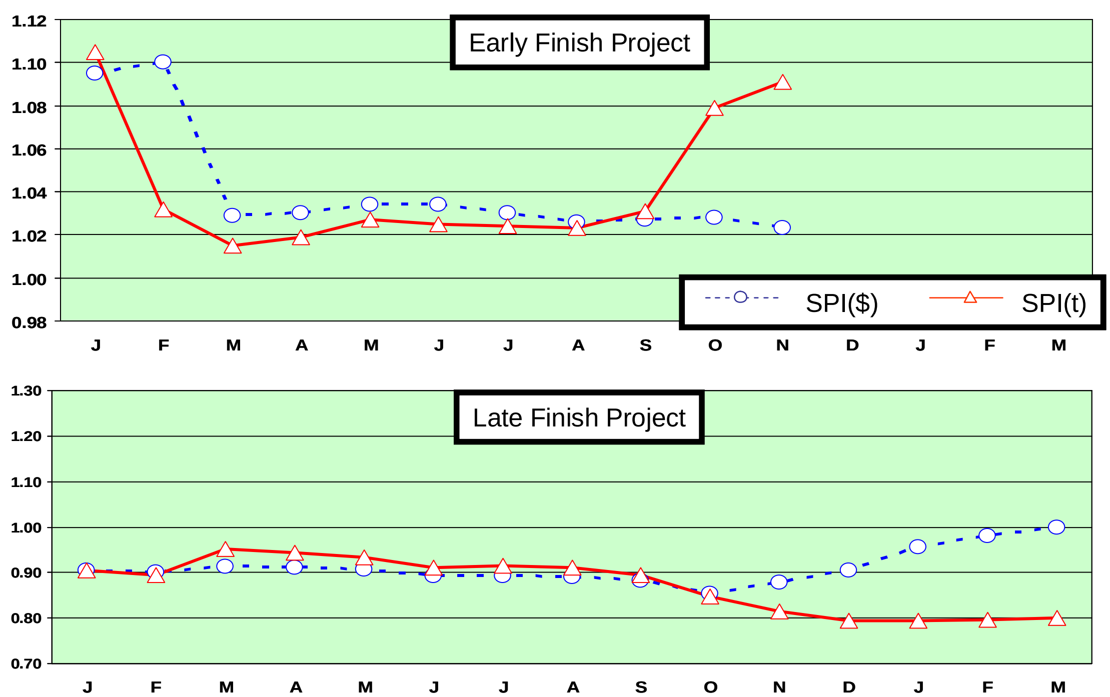


Figure 6. Notional Data – SPI($) & SPI(t) Comparison

For the late completion, the graphical trends of SV($) and SV(t) parallel for the first 70 to 80 percent of the performance time, just as they did for the early finish project. SV($) begins to decrease its variance in November, and concludes, nonsensically, with zero variance at project completion in March. We know otherwise, ….*the project completed 3 months late!!* In contrast to the behavior of SV($), SV(t) continues to increase from November through March, concluding with a value of negative 3 months. The Earned Schedule indicator, SV(t), yields calculated values which equal the project performance at completion for both the early and the late finishing projects.

In Figure 6, we observe the behavior of SPI($) and SPI(t) for both the early and late projects. For the early project, it is seen that SPI($) and SPI(t) track fairly well until October, with the exception of February. The SPI(t) value for February is less than SPI($) because the ES calculation method takes into account the increase in resources planned for March, whereas the EV method does not. In my opinion, the SPI(t) value for February better portrays the actual schedule performance in relation to the performance baseline. A similar observation is made for the comparison of the SV($) to SV(t) for the early project; SV($) increased from January to February, while SV(t) decreased.

Similarly for the late project, the SPI values for the two calculation methods are comparable through October, and then show divergence from November until project completion in March. Beginning in November, SPI($) starts its climb to the concluding value 1.0 …*its anomalous perfect ending*. Contrary to the behavior of the SPI($) indicator, SPI(t) provides useful numbers through the project's conclusion.

Summary and Conclusions

From the time of the development of Earned Value Management (EVM) indicators, it has been known that the schedule indicators are flawed and exhibit strange behavior over the final third of the project, when performance is poor. For this reason, the schedule indicators have not been viewed by project managers as being as reliable as the indicators for cost. Consequently, the management of cost has been emphasized over schedule.

This paper has presented the concept of Earned Schedule (ES), with its accompanying computation methods for Schedule Variance (SV(t)) and Schedule Performance Index (SPI(t)). Notional data for PV and EV were used to demonstrate the proposed computation methods. Then, subsequently, the computed values from the ES methods were compared, numerically and graphically, to the values computed using the EVM formulas.

The analysis indicates that the aberrant behavior of the EVM schedule indicators, SV and SPI, is overcome by employing the Earned Schedule (ES) computation methods. The application of Earned Schedule provides a set of schedule indicators, which behave correctly over the entire period of project performance.

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About the Author

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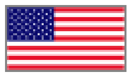
Author



Walt Lipke retired in 2005 as deputy chief of the Software Division at Tinker Air Force Base. He has over 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 USA 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 (ΣΠΣ). Lipke achieved distinguished academic honors with the selection to Phi Kappa Phi (ΦΚΦ). 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 recently selected for the 2010 Who's Who in the World. He can be contacted at waltlipke@cox.net.