



EARNED SCHEDULE

An emerging Earned Value technique

January 2010

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Preface

The main purpose of the APM's Specific Interest Groups (SIGS) is to act as a forum for discussion. These discussions are normally about how to turn the theory into practice through the development of tools and techniques. Occasionally the discussion turns to new emerging ideas or techniques that SIG members bring to their meetings to share and discuss.

A case in point is Earned Schedule which has slowly emerged since 2000. Earned Schedule is a technique for calculating time-based estimates at completion using your existing EV data in a different way to those already defined in either the EV lexicon of *Earned Value Management: APM Guidelines* or the US ANSI 748 Earned Value Standard.

The technique has largely been championed by Walt Lipke in the US and Kym Henderson in Australia. Prophets in their own lands are often damned and this was no exception. The UK offered a non-judgmental platform and interest has slowly but surely grown.

The ES toolset has been made freely available at www.earnedschedule.com and used by several people in several organizations in several countries on several projects with encouraging results.

So it could be a new additional tool. It might work - it might not. We need to find out by asking a larger community to try it out and to share their experience. We now need more evidence. We need to know if we have more than snake-oil or wishful thinking here. The APM EV SIG thinks that what has happened to date merits a further look, so that Earned Schedule can either be recommended for inclusion within the APM Body of Knowledge or not. The feedback provided will inform a review of evidence to date in late 2010.

This booklet is the APM EV SIG's way of encapsulating current thoughts on this topic (Earned Schedule) in such a way that a common interpretation of ES can be agreed and evaluated meaningfully by the project management community. It is a pamphlet; neither a guideline nor a standard. A standard or guideline will only be recommended when more evidence is available to support the theory. So be critical in your use of this booklet and have your wits about you when assessing it. Record successes as well as failure and tell us about it. We will collate and report findings. It is just as important to share bad news as well as good.

Steve Wake
Chairman APM Earned Value Management
Specific Interest Group

Introduction

Earned Schedule (ES) is an additional calculation for use with Earned Value. It's neither difficult nor time consuming. It's not that new either, having been used informally since the early days of earned value¹.

The theory, technique and calculation has been formalised by Walt Lipke². Kym Henderson validated the technique and extended its use to forecasting using current projects in the USA, Australia and the UK since 2003³. The ES technique has also been validated by using data from projects already completed (and in some cases, cancelled) both in the public and private sectors. Research is still ongoing to validate the use of ES – the evidence suggests, so far, that this is better than 'organic interpretation' - also known as guesswork - but not necessarily better than using existing EV reporting techniques to their full potential. Both real and simulated data has shown the ES technique to be more accurate when compared to other predictive statistics⁴.

It is, in essence, an extension to Earned Value and another project control technique to be used in conjunction with existing methodologies. The most important development in ES is its ability to more accurately determine the completion date for projects that are behind schedule (or will deliver later than planned.) ES uses EV performance data to generate the time-based information and as with EV, uses very similar calculations to predict future performance. Earned Schedule can be used to "drill-down" through the project's Work Breakdown Structure (WBS), in much the same way as Earned Value, to identify where deficiencies or constraints may exist and where future rework may be needed, if current performance does not change.

¹ "The trouble with Earned Schedule", Measurable News, Fall 2008, Issue 4, pp28-30, Abba W

² "Schedule is different, *CrossTalk*, December 2003: pp21-24., Lipke W

³ "Measuring the Accuracy of Earned Value/Earned Schedule Forecasting Predictors," The Measurable News, Winter 2007-2008: 26-30 [Vanhoucke & Vandevoorde]

⁴ "A Simulation and Evaluation of Earned Value Metrics to Forecast Project Duration", Journal of Operations Research Society, October 2007, Vol 58: 1361-1374 [Vanhoucke & Vandevoorde]

Applicability

The Earned Schedule document should be treated as a discussion document and a supplement to *Earned Value Management: APM Guidelines*. Due to the nature of Earned Schedule using EV data to produce metrics in terms of time, it is essential that EV is fully understood and appreciated before applying the ES technique. With this in mind the applicability of this document is to support an addition to EVM.

Basic requirements for Earned Schedule

Earned Schedule metrics are calculated from Earned Value data: it's therefore important that Earned Value data is available, namely:

- Earned Value - BCWP (also known as EV)
- Actual Costs - ACWP (also known as AC)
- Planned Value - BCWS (also known as PV)

In the rest of this guide, we'll be using EV, AC and PV instead of the 4 letter abbreviations. We'll also introduce the new terms for Earned Schedule (ES) and Actual Time (AT). Before any of this can be achieved its essential that section 3 of *Earned Value Management: APM Guidelines* is understood and applied.

What is Earned Schedule?

1.1 Earned Schedule principles

The basic principle of Earned Schedule is simple:

Identify the time at which the amount of Earned Value (EV) accrued should have been earned.

Once this value has been determined, you can use the data to provide some more useful information that can be visually displayed – and start taking action where needed. To calculate Earned Schedule, you need just three variables; EV, PV and AT. The remaining calculations, which are very similar to those already existing in EV, can be performed using this data. For a list of the Earned Schedule calculations see Table H1 in Appendix H to this guide.

The following diagram shows how Earned Schedule is calculated.

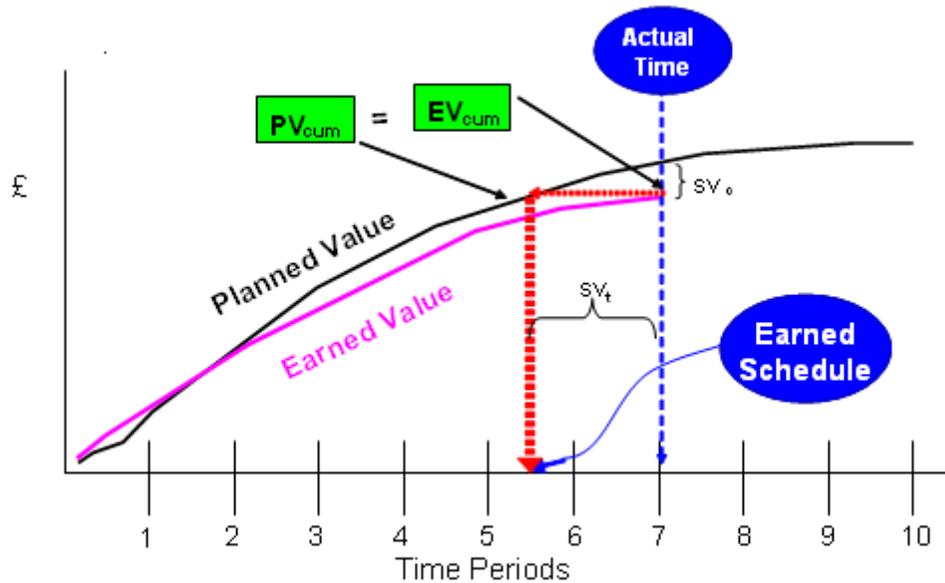


Figure 1 – Earned Schedule Chart

1.2 Earned Schedule benefits

There are a number of benefits that come from using Earned Schedule, the main benefits are;

- It provides an estimate of duration and milestone completion dates – especially for late-running activities.
- The method provides forecast indicators much in the same way as EVM.
- Project and Programme Managers have another schedule analysis tool that potentially improves the confidence in statistically forecasting delivery dates – especially for projects and programmes that are behind schedule.
- As with standard EVM, Earned Schedule integrates and supports your risk management activities – especially when justifying the need for schedule reserve, not just management (financial) reserve.
- As with standard EVM, ES facilitates drill-down to the areas of the schedule that need management attention.
- ES also provides early warning out of sequence activities by the use of the 'p' factor.
- ES makes a contribution to trend analysis; it can be used to highlight trends in milestone slippage and be superimposed with contract delivery deadlines, risk confidence limits and benefit realisation data to provide a more comprehensive picture of project/programme performance.
- Last, and by no means least, you don't need any additional data to perform Earned Schedule calculations. The existing Earned Value data is all you need; you're just using it in a different dimension.

1.3 Points to note (words of warning)

- Check input data is coming from a stable baseline and that the project is not mortgaging work (moving scope into the future).
- The project is not masking variances by making large changes and that **all** changes are authorised, plus the number & size of changes is small.
- Check that data at the Beginning Of Period (BOP) is the same as End Of Period (EOP). If not, check that changes have been authorised and are not amazingly large.
- Check that processes and procedures are still being adhered to. (Are you doing what you said you'd do?)
- Make sure that the output data has been verified and validated. If the application is bespoke or custom built, then you may need to spend more time checking and locking up/down all or part of the application to minimise errors.
- Also be aware of changing phases in a project lifecycle. Predictions based upon an "easy" phase may not carry forward into a "hard" phase.
- How the data is broken up may also impact the ability to forecast.
- ES is not a replacement for existing Project Control methodologies; it is an emerging extension of the existing EVM methodology and as such should be used in conjunction with other project performance indicators.
- Don't ignore other techniques such as critical path analysis, Schedule Risk Analysis (SRA), Cost Risk Analysis (CRA) and cost-benefit analysis.
- Schedule Variance is still an important number and can still be used to predict completion dates and compare the results to the ES method – so don't forget it.
- Remember: You should be looking for trends, not just numbers.

1.4 Understanding Earned Schedule

The graph below shows at the end of the 7th time period (this is usually measured in either weeks or months) the cumulative amount of value earned (EV_{cum}). The Earned Schedule value is calculated by projecting the EV curve (the horizontal dotted red line) until it meets the cumulative Planned Value (PV_{cum}) curve. This is the point at which $EV=PV$, the time at which the EV amount should have been earned. By tracing this point on the PV_{cum} curve to the x-axis (the vertical dotted red line) you determine the amount of time "earned" schedule. In the graph, this value is approximately 5.5 months.

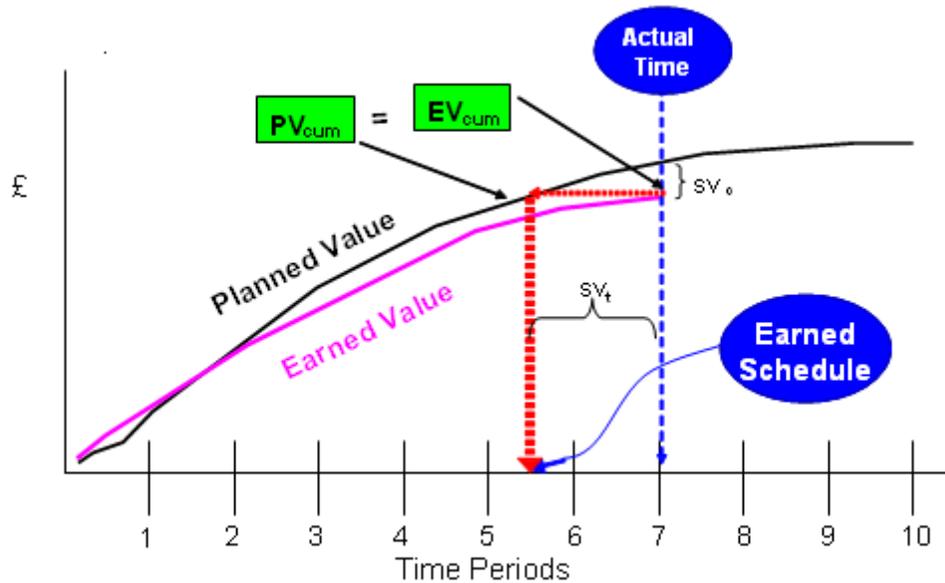


Figure 2: Calculating Earned Schedule

You may have noticed that this is a very approximate way of calculating our Earned Schedule. There is a formal method that can be used to calculate ES:

ES = C + I where:

ES = Earned Schedule

C = number of complete time periods for which $EV_{cum} \geq PV_{cum}$ (BCWP \geq BCWS)

The way in which the number of complete time periods is calculated can be seen in Annex B and can be completed either manually or automatically – for example by use of a spreadsheet.

And the increment I

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

With PV and EV keeping their original meanings

Using our previous graph, you'll see that if we use the equation above, we have 5 periods where our EV value is \geq to PV. That leaves the calculation for the increment. Let's zoom into the part of the graph near the top of the EV curve to see how the increment is calculated:

Calculating the Increment I

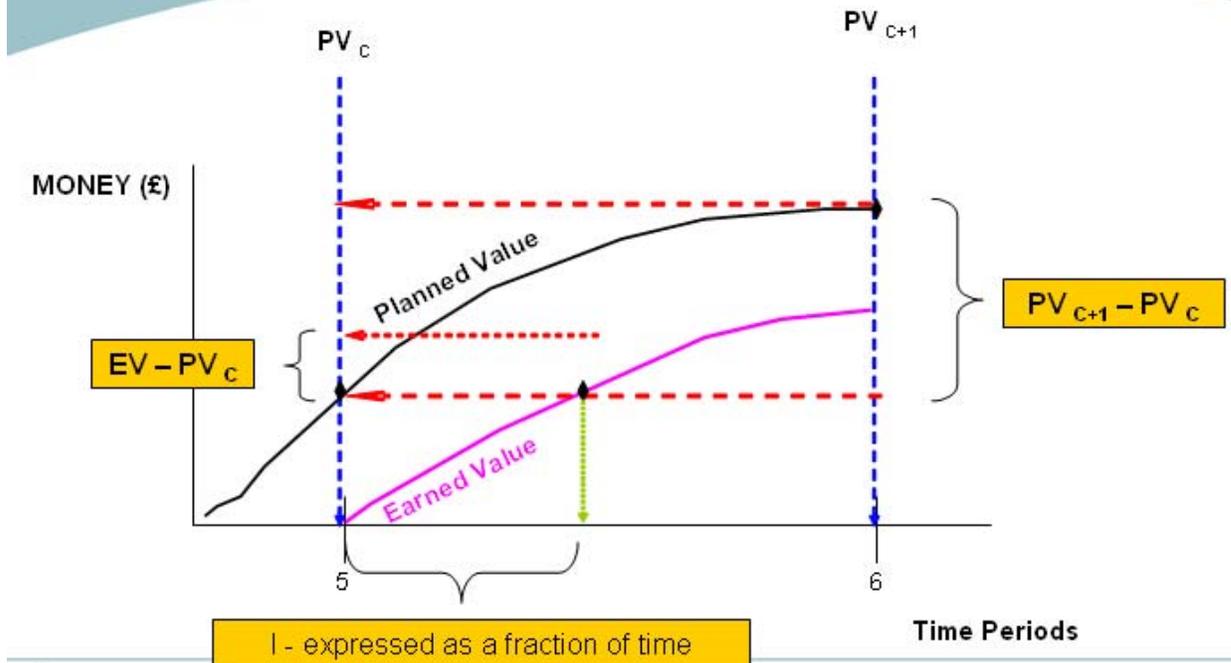


Figure 3: Calculating the increment I

You can see that the upper half of the fraction (known as the numerator) is shown on the left of the graph. Both terms of the numerator are taken from the two data points shown with the arrows (it's also marked by the red dotted lines.)

The bottom of the equation (the denominator) is shown on the right of the graph. In this case, the values for PV_{C+1} and PV_C are represented as PV_6 and PV_5 respectively, the planned values for periods 5 and 6 (months or weeks – it doesn't matter, as long as the values are used consistently throughout.)

By dividing the left hand equation by that on the right, we end up with the increment value – this is expressed not in terms of money but time. In the graph, we don't have actual values, but you can see that the fraction is approximately 0.5 months and is represented by the vertical green dotted arrow; take note the chart is not to scale.

So from our ES equation, $ES = C + I$, we have the following:

$C = 5$ (the complete number for periods where $EV \geq PV$)

And $I = 0.5$

Therefore $ES = 5.5$.

Now, compare this to the original graph. You'll remember that the Actual Time (AT) was 7 periods. That means we should have done the equivalent of 7 months' worth of work by now. Only 5.5 months has been completed. So, the project is 1.5 months behind schedule. Something needs to be done to bring the project back on track. Appendix B has a worked example to demonstrate how ES actually works. To reinforce the method, let's use the $ES=C+I$ equation with some of the data from Annex B.

Let's use the second data point, as shown in figure A3. We won't use the first data point, as comparisons to zeros can be a little confusing.

To calculate C we note that the value for EV_{cum} second data point is 180. This is less than the PV_{cum} , set at 200 for the second increment of time on this project. So, we can't say that we've earned two period's worth of effort. However, the EV_{cum} value is greater than that for month 1 (105.) Time wise, we must have earned at least 1 period's effort – but not enough to claim two periods. So, $C=1$ in this instance.

To calculate the increment, we use $I = (EV - PV_C) / (PV_{C+1} - PV_C)$

Using the values above and putting these directly into the equation and taking the numerator first;

$$(EV - PV_C) = 180 - 105$$
$$(EV - PV_C) = 75$$

And the denominator is $(PV_{C+1} - PV_C)$

$$(PV_{C+1} - PV_C) = 200 - 105$$
$$(PV_{C+1} - PV_C) = 95$$

So the increment $I = 75/95$.

$$I = 0.789$$

The total $ES = C+I$

$$ES = 1 + 0.789$$

So $ES = 1.789$ periods. It should be 2. Therefore, we are behind by 0.211 periods.

Appendix A – A real example

This example uses real data from a project. It has been sanitised to protect the project it was taken from and to allow you to understand how ES is calculated and explain some important differences between ES and EV on late-finish projects. If you would like a copy of the original ES calculator, you can download it from www.earnedschedule.com. The data used in this example is also available as part of the ES calculator available on the website. We'll go through four complete calculations and then skip to the final data entry and project conclusion.

After each of the calculations, we'll draw a graph to demonstrate the differences between EV and ES for a late-finish project.

In the first month the data point is entered in the "EV_{cum}" column. The spreadsheet does the rest. You can see that the amount of EV is less than the PV for the first month. As a result, our ES equation (ES=C+I) has C=0. The numerator is calculated as EV_{cum}-PV. In this instance, this is simple; 95-0 as is shown in the column marked 'Numerator'.

The denominator is just as straightforward. It's the difference between successive PV data points. In this case, 105-0. By dividing the numerator by the denominator, we get the value in the 'InterpVal' column. The total ES value can now be found by adding C to I. Earlier, we saw that C=0 for this instance. So the cumulative ES value (ES_{cum} in column G) is the same value as column F, the increment I.

EV cum	PV cum	# EV=>Pv	Numerator	Denominator	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	SV(t)cum	SV(£) cum
0	0									0			
95	105	0	95	105	0.905	0.905	0.905	0.905	0.905	1	-0.095	-0.095	-10
	200	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	515	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	845	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	1175	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	1475	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	1805	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	2135	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	2435	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	2665	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	2760	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	2823	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
		PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
		PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A

Figure A1: First data point calculation

What does this look like graphically? Well...it's only one data point. It looks like this:

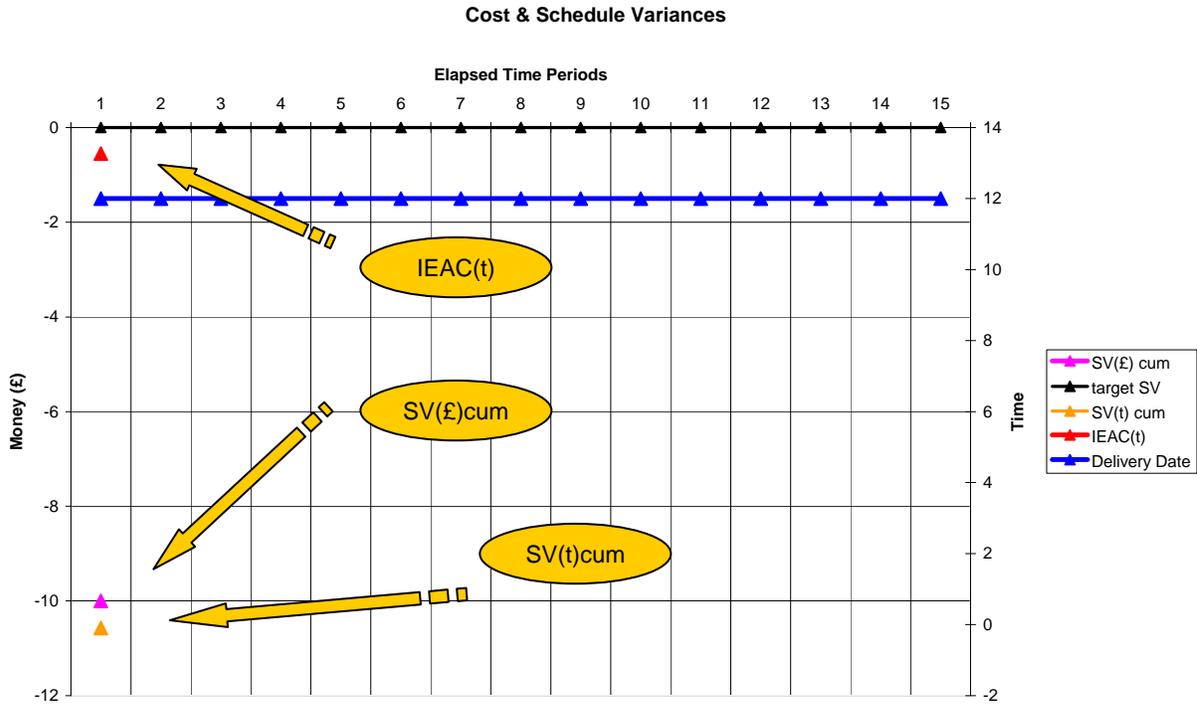


Figure A2: Graph of 1st data point

The point of interest is in the bottom left of the graph, as indicated by the pointer. The other data point just above it is the "classical" schedule variance 'SV(£)cum' and we'll compare these two as the project progresses. You'll notice that there are other lines being shown on the graph. These will be introduced as the picture builds. Note that $SV(£)_{cum}$ and the target SV line are plotted on the left hand vertical axis and the values for SV(t) and IEAC(t) are plotted on the right-hand axis.

Calculating the second ES data point is just like the first. There are a few differences that need explaining.

EV cum	PV cum	# EV=>Pv	Numerator	Denominator	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	SV(t)cum	SV(£) cum
0	0									0			
95	105	0	95	105	0.905	0.905	0.905	0.905	0.905	1	-0.095	-0.095	-10
180	200	1	75	95	0.789	1.789	0.885	0.885	0.895	2	-0.115	-0.211	-20
	515	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	845	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	1175	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	1475	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	1805	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	2135	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	2435	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	2665	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	2760	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	2823	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
		PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
		PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A

Figure A3: Second data point calculation

You can see in column C that the value '1' exists, that's because the amount of EV is less than 200 in month 2, but greater than 180 in month 1. Thus, C=1 in this instance. The

increment is calculated in the same way as before. The total ES value comes from adding values in columns C and F. The graph, along with the second data point, now looks like this:

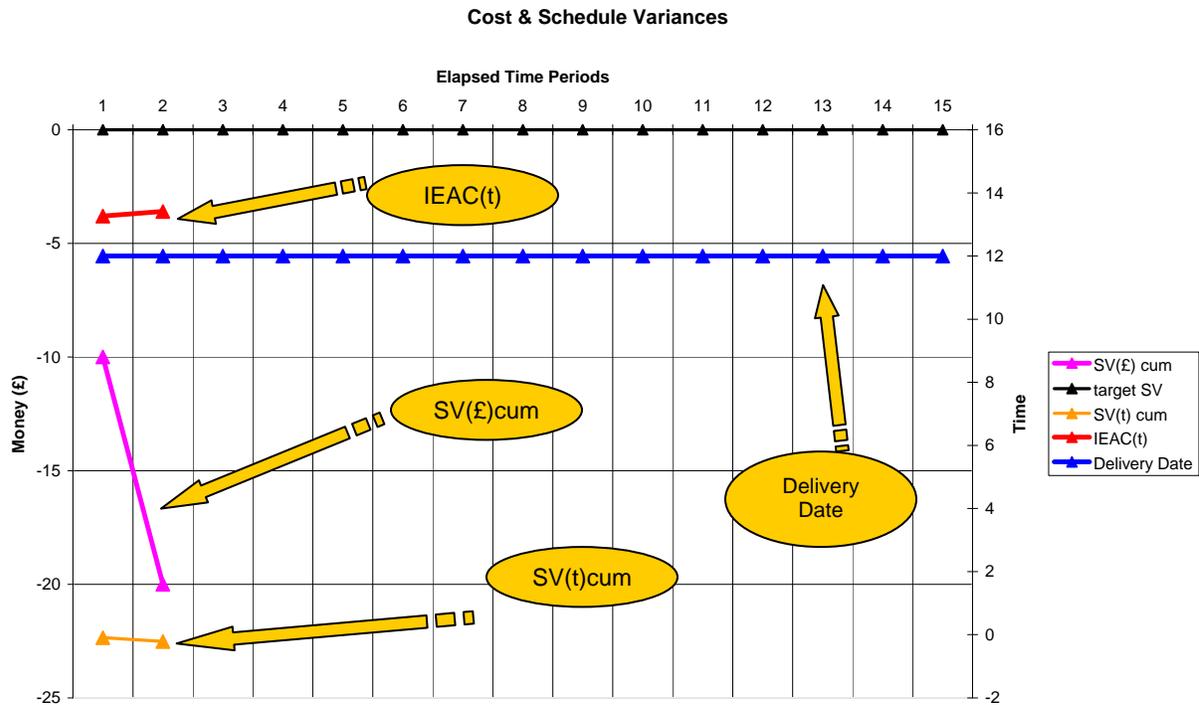


Figure A4: graph of second data point

The two data lines for $SV(\pounds)_{cum}$ and $SV(t)_{cum}$ indicated above need explaining. Both deal with schedule variance or SV. One is the "classical" schedule variance, measured in money, whilst the other is measured in time. The two SV values are calculated in much the same way:

Earned Value (EV)	Earned Schedule (ES)
Schedule Variance $SV(\pounds)$	Schedule Variance $SV(t)$
= EV-PV Earned Value – Planned Value	= ES-AT (or Earned Schedule – Actual Time)
Schedule Performance Index (SPI) = EV/PV	Earned Schedule Performance Index $SPI(t)$ = ES/AT (Earned Schedule/Actual Time)

Table A1: Schedule Variance: comparison between ES and EV

The similarities jump out at you. Annex H has a more detailed list of ES equations; notice that they look very similar, with one exception. The ES equations do not refer to Actual Costs; it's not used in any ES calculation.

Let's put in the third set of EV data and start to compare the two SV values.

EV cum	PV cum	# EV=>Pv	Numerator	Denominator	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	SV(t)cum	SV(£) cum
0	0									0			
95	105	0	95	105	0.905	0.905	0.905	0.905	0.905	1	-0.095	-0.095	-10
180	200	1	75	95	0.789	1.789	0.885	0.885	0.895	2	-0.115	-0.211	-20
470	515	2	270	315	0.857	2.857	1.068	1.068	0.952	3	0.068	-0.143	-45
	845	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	1175	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	1475	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	1805	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	2135	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	2435	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	2665	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	2760	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
	2823	PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
		PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
		PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A
		PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	#N/A	#N/A

Figure A5: 3rd data point calculation

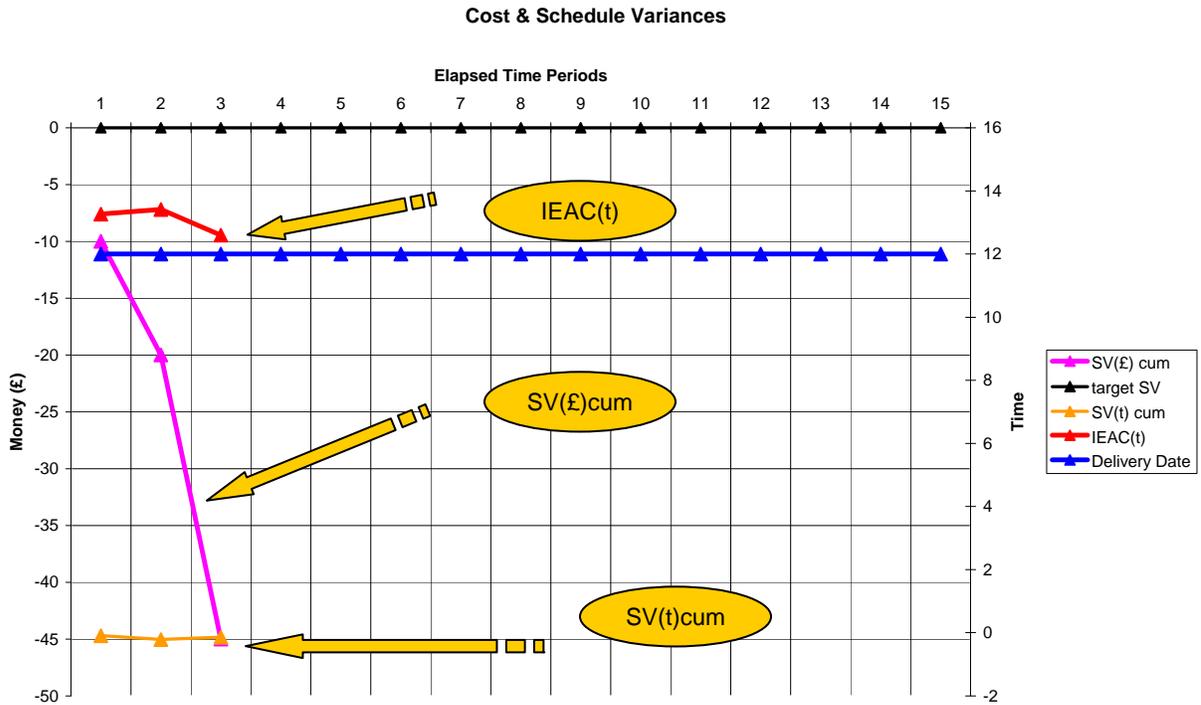


Figure A6: Graph of 3rd data point

And the fourth data point:

EV cum	PV cum	# EV=>Pv	Numerator	Denominator	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	SV(t)cum	SV(£) cum
0	0									0			
95	105	0	95	105	0.905	0.905	0.905	0.905	0.905	1	-0.095	-0.095	-10
180	200	1	75	95	0.789	1.789	0.885	0.885	0.885	2	-0.115	-0.211	-20
470	515	2	270	315	0.857	2.857	1.068	1.068	0.952	3	0.068	-0.143	-45
1065	845	4	220	330	0.667	4.667	1.810	1.810	1.167	4	0.810	0.667	220
1175		PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	SV(t)cum	#N/A
1475		PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	SV(t)cum	#N/A
1805		PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	SV(t)cum	#N/A
2135		PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	SV(t)cum	#N/A
2435		PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	SV(t)cum	#N/A
2665		PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	SV(t)cum	#N/A
2760		PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	SV(t)cum	#N/A
2823		PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	SV(t)cum	#N/A
		PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	SV(t)cum	#N/A
		PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	SV(t)cum	#N/A
		PV=>EV	NUM	DENOM	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	SV(t)cum	#N/A

Figure A7: 4th data point calculation

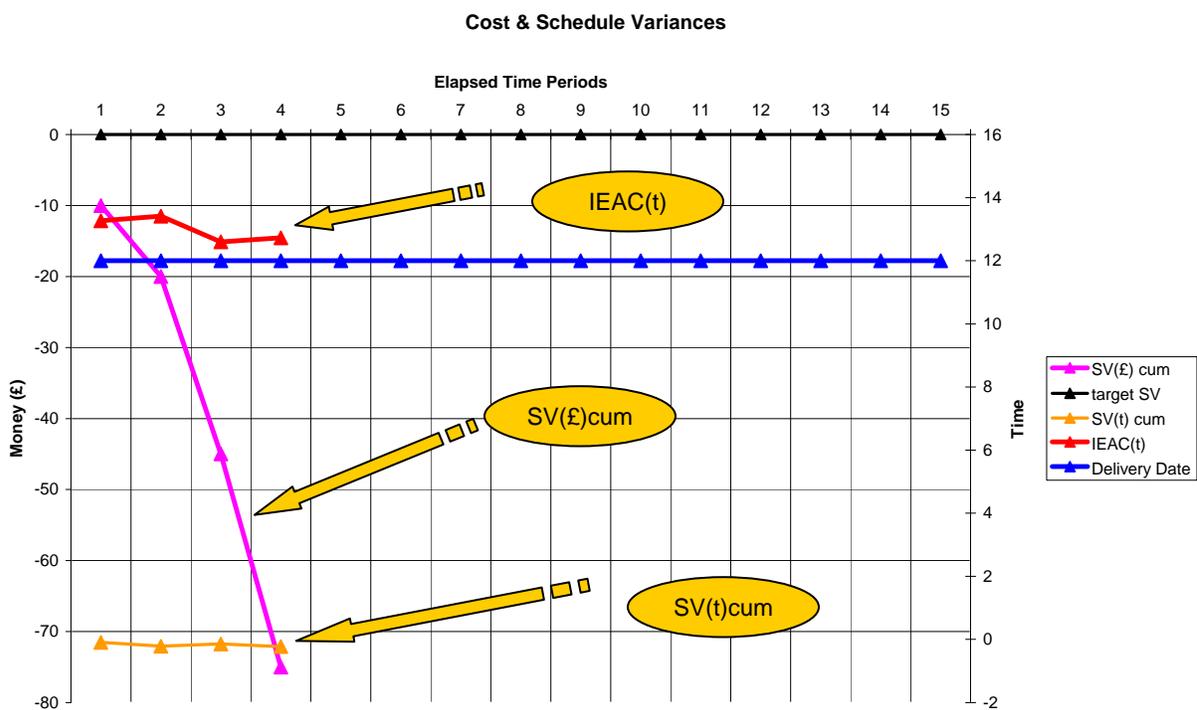


Figure A8: Graph of 4th data point

One other value that needs an explanation is the Independent Estimate At Completion date (time) (IEAC(t)). One of the most powerful attributes of Earned Value is its ability to predict a completion cost. Two important things to note:

- The prediction assumes that **current performance does not change**. Hence it's an estimate, not set in stone. The statement concerning current performance means from the point in time when the data is captured to the end of the project.
- This prediction is **no longer based on cost**. It's based on **time**.

Focusing on the IEAC(t) line, you can already see that the predicted delivery date is later than the 12 months planned (the horizontal blue line). The project manager has to do something to ensure the project keeps to its original delivery date.

Here's a comparison of two IEAC equations, as before one is based on the "classical" EV values, whilst the other is based on ES. Note as before, the similarities between the two. Moreover, the EV equation is only one of at least 12 different ways to calculate IEACs that are used by EV practitioners with their customers and stakeholders. The one shown below is the most commonly used:

Earned Value (EV)	Earned Schedule (ES)
IEAC	IEAC(t)
$EAC_1 = AC + \left(\frac{BAC - EV}{CPI} \right)$	$IEAC(t) = AT + \left(\frac{PD - ES}{SPI(t)} \right)$
Where CPI = Cost Performance Index	Where PD = Planned Duration
And BAC = Budget At Complete (the PMB)	

Table A2: Comparison of ES and EV prediction techniques

Important things to note when using IEACs:

- Decide jointly with stakeholders which IEACs you are going to use.
- Keep using the same ones. People won't get confused.
- Write the use of these chosen IEACs into any contracts you have.
- Ensure **all** stakeholders understand what you're using and why.
- Communicate to all stakeholders **what** you use the data for and **when** it's used and by **whom**.
- It may be exciting to keep influential people in the dark but in the long term it'll do you no good.

The graphs used in the examples so far do not have a cost related IEAC. We'll use another ES spreadsheet later in this guide, comparing and contrasting cost and time predictions.

Let's complete the spreadsheet and look at the final result:

EV cum	PV cum	# EV=>Pv	Numerator	Denominator	InterpVal	EScum	ESmo	SPI(t)mo	SPI(t)cum	AT	SV(t)mo	SV(t)cum	SV(\$) cum
0	0									0			
95	105	0	95	105	0.905	0.905	0.905	0.905	0.905	1	-0.095	-0.095	-10
180	200	1	75	95	0.789	1.789	0.885	0.885	0.895	2	-0.115	-0.211	-20
470	515	2	270	315	0.857	2.857	1.068	1.068	0.952	3	0.068	-0.143	-45
770	845	3	255	330	0.773	3.773	0.916	0.916	0.943	4	-0.084	-0.227	-75
1065	1175	4	220	330	0.667	4.667	0.894	0.894	0.933	5	-0.106	-0.333	-110
1315	1475	5	140	300	0.467	5.467	0.800	0.800	0.911	6	-0.200	-0.533	-160
1610	1805	6	135	330	0.409	6.409	0.942	0.942	0.916	7	-0.058	-0.591	-195
1900	2135	7	95	330	0.288	7.288	0.879	0.879	0.911	8	-0.121	-0.712	-235
2150	2435	8	15	300	0.050	8.050	0.762	0.762	0.894	9	-0.238	-0.950	-285
2275	2665	8	140	300	0.467	8.467	0.417	0.417	0.847	10	-0.583	-1.533	-390
2425	2760	8	290	300	0.967	8.967	0.500	0.500	0.815	11	-0.500	-2.033	-335
2555	2823	9	120	230	0.522	9.522	0.555	0.555	0.793	12	-0.445	-2.478	-268
2695		10	30	95	0.316	10.316	0.794	0.794	0.794	13	-0.206	-2.684	-128
2770		11	10	63	0.159	11.159	0.843	0.843	0.797	14	-0.157	-2.841	-53
2823		12	0	-2823	0.000	12.000	0.841	0.841	0.800	15	-0.159	-3.000	0

Figure A9: completed ES example calculation

You'll note that an extra 3 rows have been added, that's because the project was running late. I'll discuss some of the other figures after looking at the graph. This is where the biggest differences occur.

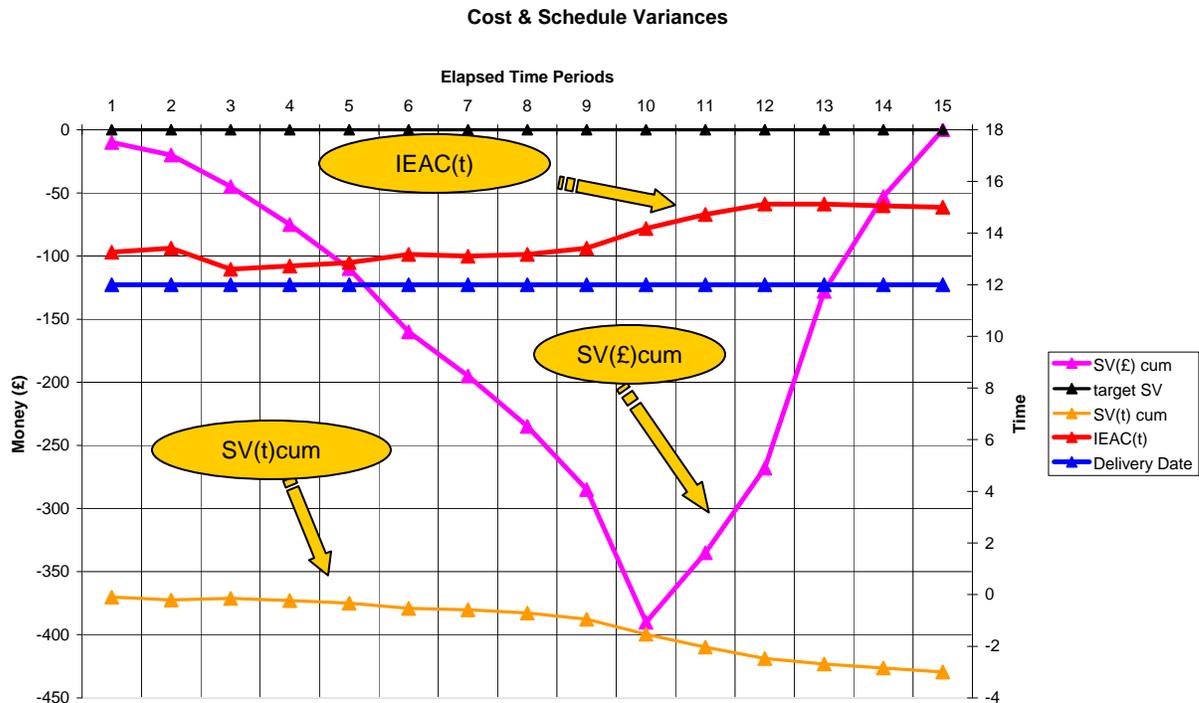


Figure A10: Graph of complete example calculation

The most important item to note here is the differences in the SV lines. The "classical" SV line (in the pink) shows a typical 'v' curve. It implies, because of the way in which it is calculated, that schedule variance is improving after month 10. It will slowly start to return to zero, as it charts the difference between EV and PV.

Now look at the SV(t) line. Our Earned Schedule SV is telling us a completely different story. Reading from the right-hand vertical axis, it shows that the completion time of 12 periods is entirely inaccurate. At month 10, when the ES curve starts its upward climb, the new SV is telling us that the project is already some 2 months late. This is confirmed when you look at the red line. This is showing a completion time of approximately 14 periods. Seems reasonable, as 12 months (original duration) + 2 months (project delay) = 14 months. If the **project performance doesn't change** – either better or worse- that's when the project will deliver. In addition, you can see from the spreadsheet that at periods 12, we would have a singularity in the IEAC calculation (a divide by zero occurs) as the original duration and actual time are the same. By changing the duration from 12 to 15 periods (the final project duration) the sums still work properly.

The graphs above show some of the EV data as variances and do not describe the entire EV and PV curves. The following graph shows these together in the 'classical' way. You can use this graph to manually estimate any delays to the project completion date. You

may want to compare the results you get from this method with those using the $SV(\pounds)_{cum}$ method shown below and the results from the ES method, too.

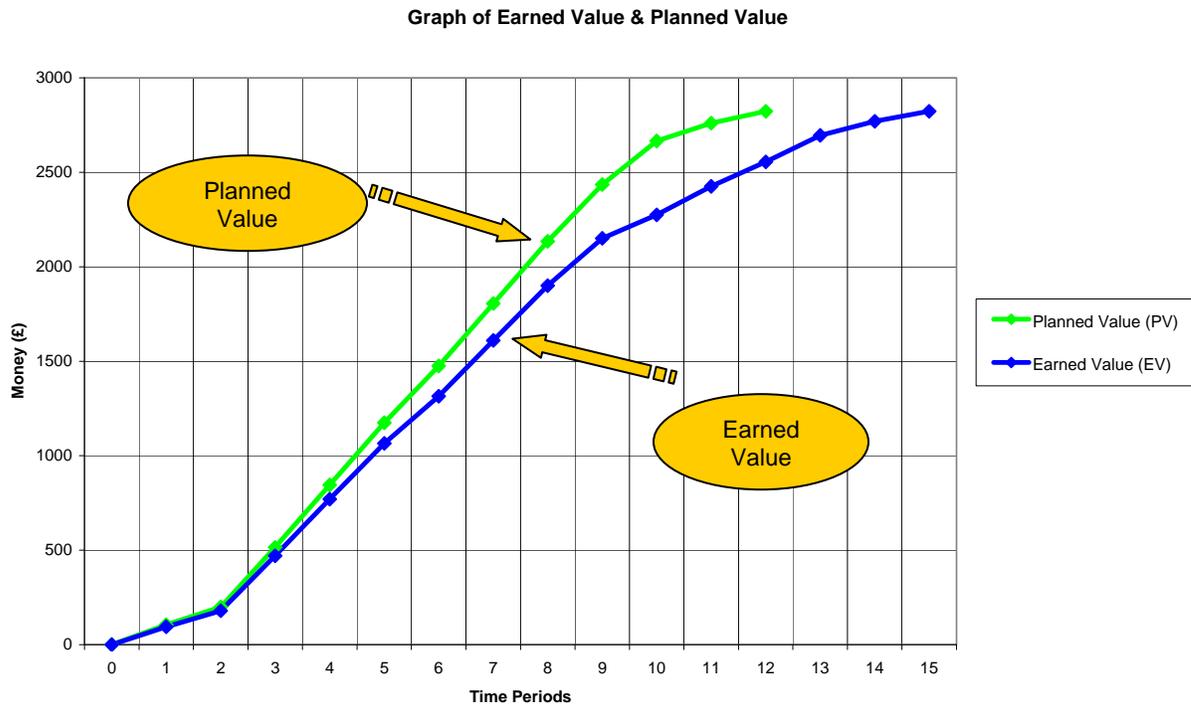


Figure A11: Graph of PV and EV for the worked example

I know that some readers will use the $SV(\pounds)_{cum}$ line as a method of predicting the project end date. So, to be fair and equitable to the use of this technique, I include the following analysis. You will note from the graph below (which is the same as figure A8 in terms of data points) that I've included a linear trend line. It predicts, fairly accurately, that the project will end at the end of period 15. The ES method won't predict this until period 11. However, the linear trend line does not move from the 15 week point, no matter how the EV cum changes period by period. Both the ES line and $SV(\pounds)$ trend line indicate that the project is late and the project manager must act to prevent further slippage.

Cost & Schedule Variances

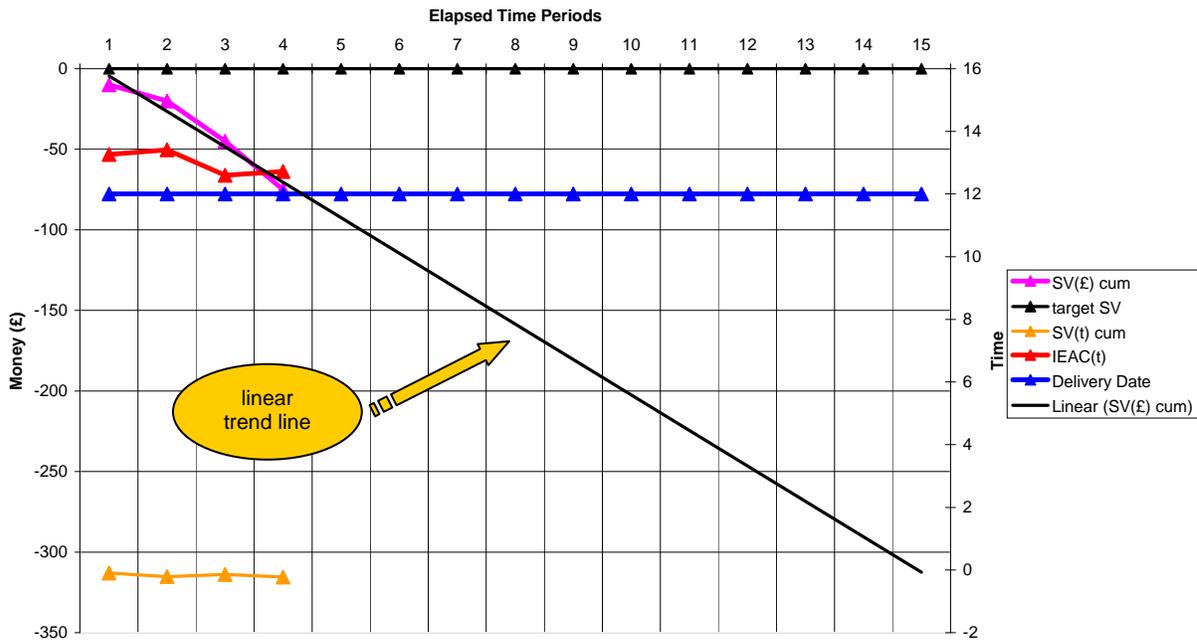


Figure A12: Graph of $SV(\pounds)_{cum}$ showing linear trend line

One benefit that the ES method has over the $SV(\pounds)_{cum}$ method, is the ability to calculate all ES data automatically from the existing EV data. The $SV(\pounds)$ trend line takes a long time to produce and needs care in its use and interpretation. To help demonstrate this, I add the following graph using the same data as above, but I've increased the number of time periods out to 20. You can see that, even though the data hasn't changed, the $SV(\pounds)$ trend line seems to indicate that the project will finish at period 20. Two lessons from this:

- Check the validity of the data and the time periods being used.
- Where possible, use more than one method to determine the same value or criterion.

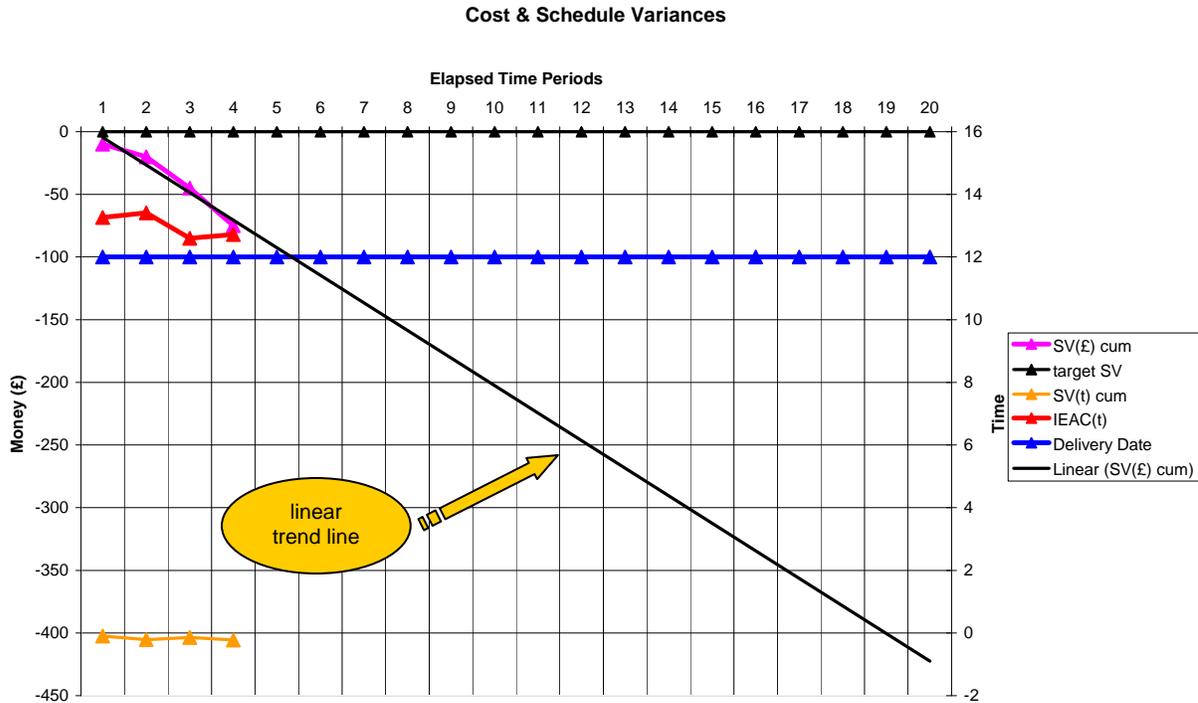


Figure A13: Graph of $SV(\pounds)_{cum}$ showing extended linear trend line

Appendix B – Accuracy of the Earned Schedule method

As with any mathematical method, there are errors introduced when you use any form of linear interpolation. Quite rightly, both supporters and yet-to-be converts to the ES technique have questioned the technique, so here are the FAQs.

- The PV curve is an S-Curve. Does the linear interpolation introduce a large ES error?
- Is the ES error largest where the S-Curve is steepest?
- What affects the accuracy of the ES calculation?

Good questions. But how do we answer them? The diagram below will help explain this.

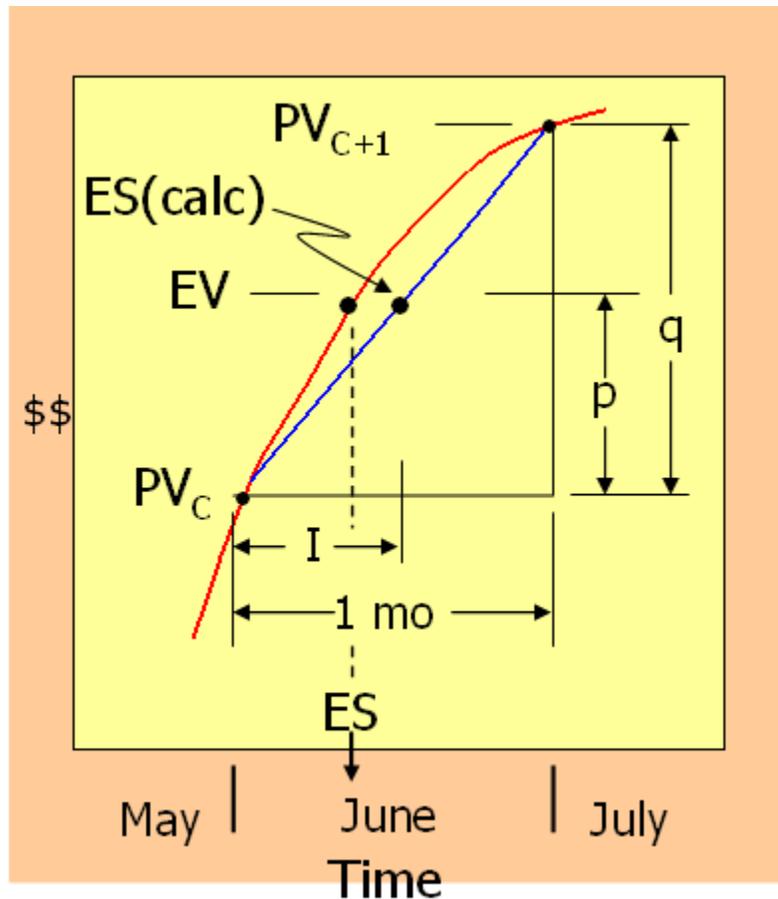


Figure B1: Earned Schedule Accuracy (reproduced by kind permission of Lipke & Henderson)

This graph, which is almost identical to the one we saw earlier, shows two lines. The red line is the Planned Value curve, whilst the blue curve shows the result of the ES interpolation calculation.

$$\begin{aligned} \text{ES} &= \text{Number of whole months (C) + the increment on the red curve (F)} \\ &= C + F \end{aligned}$$

$$\text{ES(calc)} = C + \text{calculated increment (I) on the blue line}$$

$$\text{Therefore, Error } (\delta) = I - F$$

$$\text{And hence \% error} = \frac{|\delta|}{C + F}$$

So, as the value of C gets larger as you obtain more data from successive data points, the % error will decrease.

What about when the curve is steepest? In this instance, the gradient of the PV curve is at its highest – so its curvature is minimised. As a result, the interpolation error will also be minimised.

In summary:

- The bigger the value C becomes, the smaller the error becomes
- The more data points you have, the more accurate the ES value is

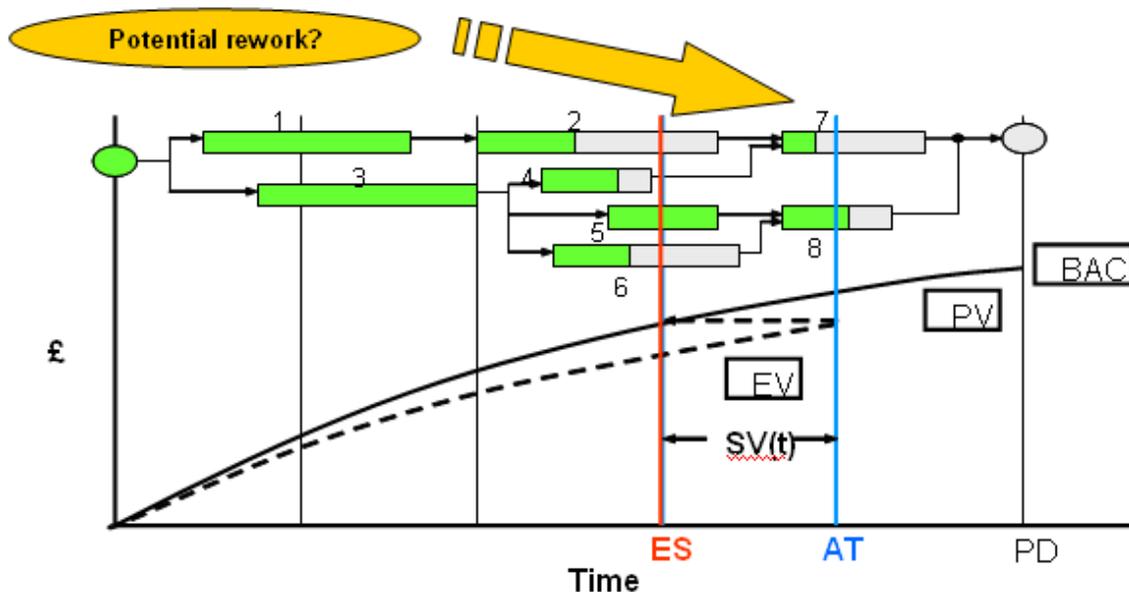
Be careful how you interpret the ES results – best to wait until you have at least 4 time periods (weeks or months) of data for two reasons:

1. The ES interpolation errors are $<3\%^5$
2. The EV (and hence ES) data won't have settled and you won't be able to detect any trends.

Appendix C – Schedule adherence

One additional benefit of using ES data is using the data to understand if the activities you intended to do are being done in the right order. Why is this important? Some organisations using EVM will produce metrics for their customers and stakeholders that show the EV_{cum} claimed is following the PV_{cum} curve very closely and they're performing well. It's a clever ruse.

What's actually happening is tasks are being started ahead of time and some value being claimed (sometimes using a different measurement technique) to keep the figures looking healthy. This is because some work packages aren't earning value at the rate they should be. So by starting another work package ahead of schedule we can claim additional value. The diagram below shows what is happening in this instance:



⁵ "A Case Study of Earned Schedule to do Predictions," The Measurable News, Winter 2007-2008: 16-18 [Hecht]

Figure C1: Schedule Adherence

Activity 7 has started before both activities 2 and 4 have completed. Assume that activity 2 deals with the design and production of a critical item (for example, an engine that needs to be integrated into a vehicle.) In addition, assume that activity 7 is the integration of that engine into the vehicle. What happens if the design of the engine needs to change (for whatever reason) before integration? There will be some rework needed on activity 7. As a result, the project will need to spend more time and money reworking documents, designs and components. Delivery will be later, not just because the original performance is less than planned, but because rework is now needed to correct the problems caused by work being started out-of-sequence. How can you forecast this? You can use ES data to inform you when rework is likely and how much rework is likely to be needed – as before – **if current performance does not change.**

Annex C1 – Schedule adherence and the 'p' factor

The schedule adherence factor described above is known as the 'p' factor. As with Schedule and Cost Performance Indices (SPI and CPI) the 'p' factor has a range. Take care; the 'p' factor can only range between 0 and 1. Unlike SPI and CPI it cannot exceed 1 at any time. It tells you what **order** the work is being done in – not **how much** is being done in a known time period.

Described mathematically as a ratio:

$$P = \Sigma EV_j / \Sigma PV_j$$

PV_j represents the Planned Value for a task associated with ES. The subscript j denoted the identity of the tasks from the schedule which comprises the planned achievement. The sum of all PV_j is equal to the EV accrued at AT. EV_j is the earned value for the 'j' tasks, limited by the value attributed to the planned tasks. Consequently the value 'P' represents the proportion of the EV accrued which exactly matches the planned schedule.

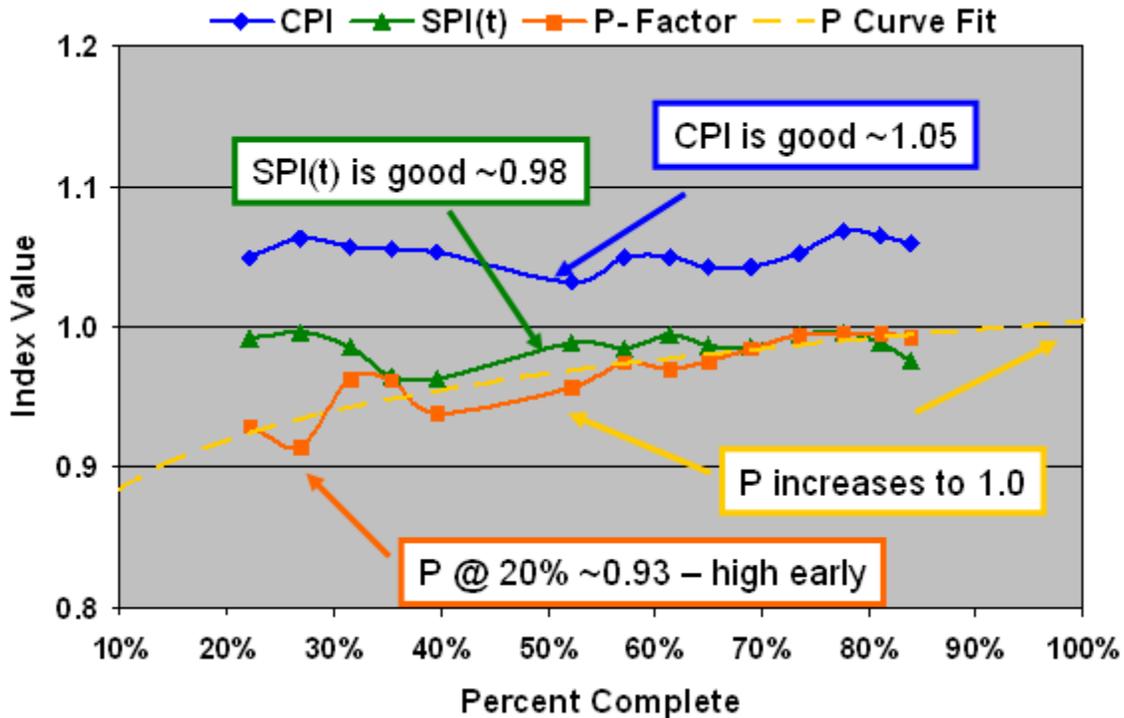


Figure C2: P-factor illustration

Appendix D: Earned Schedule software applications

There are a number of software applications currently being developed at time of writing that calculate and present Earned Schedule data. They range from spreadsheets (as developed by Walt Lipke and Kym Henderson that are available to download from the Earned Schedule website) to more sophisticated (and more expensive) applications. Deltek® are developing their COBRA© software to include ES calculations.

The main advantage of doing this within the latter type of application is to allow the user to 'drill-down' into the WBS and have access to ES data that has been automatically calculated for that specific level. If the same user were to employ the spreadsheet version to perform drill-down analysis, a large amount of manual work would have to be done to create a new spreadsheet to generate the data required for the WBS level in question.

Project Flightdeck® has developed a software application that runs as a macro within Microsoft® Project © that enables the user to calculate ES at a particular WBS level and to generate a 'p' factor for a project schedule at any level in the project. Should you wish to try it, a free trial version is [available here](#). As with any EV or ES data, just be careful with masking and washout of performance data. For example schedule variance, SPI(t) values at a lower WBS element that may be a cause for concern are not highlighted when reviewing performance of the same value at a much higher WBS element. It only tells part of the story – remember to use additional data (e.g. the schedule, cost performance reports, common sense) to get an overall picture before taking corrective action.

Appendix E: Future work with Earned Schedule

As ES is a formal numerical technique, a number of research projects are ongoing that deal with the extension of ES into other areas of project controls and project management. Advances and extensions to ES are already being used in the defence and IT industries in the following areas:

- ES and Benefits Management
- ES and confidence limits
- Interfacing Earned Schedule with risk management
- The use of ES in programme management

The next update to this document in 2010 may include reports on the results of these emerging techniques, with supporting data and analysis. The ES community relies on projects and their data to add to the growing archive of information that can be used to verify and validate developing ES techniques. If any readers wish to contribute project data, please contact either the EVM SIG chairman or you may contact ES practitioners through the earned schedule website – www.earnedschedule.com.

Appendix F: Abbreviations and acronyms

ACWP	Actual Cost of Work Performed
AC	Actual Cost
AT	Actual Time
BAC	Budget At Completion
BCWP	Budgeted Cost of Work Performed
BCWR	Budgeted Cost of Work Remaining
BCWS	Budgeted Cost for Work Scheduled
BOP	Beginning Of Period
CA	Control Account, also known as Cost Account
CAM	Control Account Manager
CBB	Contract Budget Baseline
CPI	Cost Performance Index
CPM	Critical Path Method
CPR	Cost Performance Report
CV	Cost Variance
CV%	Cost Variance percentage
CWBS	Contract Work Breakdown Structure
DB	Distributed Budget
EAC	Estimate At Completion
ED	Estimated Duration
EOP	End Of Period
ES	Earned Schedule
ETC	Estimate To Completion

EV	Earned Value
EVA	Earned Value Analysis
EVM	Earned Value Management
EVMS	Earned Value Management System
EVT	Earned Value Technique
IBR	Integrated Baseline Review
IEAC	Independent Estimate At Complete
IEAC(t)	Independent Estimate Completion Date (time)
LoE	Level of Effort
LRE	Latest Revised Estimate (same as EAC)
MR	Management Reserve
OBS	Organisation Breakdown Structure
PD	Planned Duration
PF(t)	Performance Factor (time)
PMB	Performance Measurement Baseline
PMS	Project Master Schedule
PP	Planning Package
PV	Planned Value
RAM	Responsibility Assignment Matrix
RM	Risk Management
RN	Risk Network
SoR	Statement of requirement
SOW	Statement Of Work
SPI	Schedule Performance Index
SV	Schedule Variance
SV%	Schedule Variance percentage
TCPI	To Complete Performance Index
TSPI	To Complete Performance Index (time)
UB	Undistributed Budget
VAC	Variance at Completion
VAC%	Variance at Completion percentage
VAR	Variance Analysis Report
WBS	Work Breakdown Structure
WP	Work Package

Appendix G: Earned Schedule terminology

Table H1: Earned Schedule and Earned Value Terminology

	EVM	Earned Schedule
Status	Earned Value (EV)	Earned Schedule (ES)
	Actual Costs (AC)	Actual Time (AT)
	Schedule Variance (SV)	SV(t)
	Schedule Performance Index (SPI)	SPI(t)
Future Work	Budgeted Cost for Work Remaining (BCWR)	Planned Duration for Work Remaining (PDWR)
	Estimate To Complete (ETC)	Estimate To Complete (Time) (ETC(t))
Prediction	Variance At Completion (VAC)	Variance At Completion (Time) (VAC(t))
	Independent Estimate At Completion (IEAC)	Independent Estimate At Completion (time) IEAC (t)
	To Complete Performance Index (TCPI)	To Complete Performance Index (time) (TSPI)

Metrics	Earned Schedule	EScum	ES=C+I number of complete periods [C] plus an incomplete portion (I)
	Actual Time	ATcum	AT=number of periods executed
Indicators	Schedule Variance	SV(t)	SV(t) = ES-AT
	Schedule Performance Index	SPI(t)	SPI(t)= ES/AT
	To Complete Schedule Performance Index	TSPI	TSPI = (PD-ES)/(PD-AT) TSPI = (PD-ES)/(ED-AT) Where ED = Estimated Duration
Predictors	Independent Estimate At Completion	IEAC(t)	IEAC(t) = PD/SPI(t) IEAC(t) = AT + (PD-ES)/PF(t) Where PF(t) is a time-related performance factor (for example (SPI(t)))

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