# Earned Schedule: A Breakthrough Extension to Earned Value Management

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## Abstract

Earned Schedule (ES) analysis is a breakthrough analytical technique that derives schedule performance measures in units of time, rather than cost. The same basic Earned Value Management (EVM) data points are used. Indicators, similar to those for cost, are derivable from the earned schedule measure. These indicators provide a status and predictive ability for schedule, analogous to cost. Because these metrics use time based measures, they augment traditional EVM and integrated schedule analysis. Work has also been undertaken which provides "bridging" analytical techniques between Earned Schedule and traditional integrated schedule analysis.

## Earned Value Management Basics

Earned Value Management (EVM) was created within the United States Defense Department in the 1960s and has been demonstrated over nearly four decades of usage to be a very valuable project management and control system which uniquely connects cost, schedule, and the "physical progress" achieved by the project team. EVM has allowed for the creation of quantitative project performance indicators and predictors of future performance, which project managers are able to use to objectively manage their projects and proactively take corrective actions.

Using EVM Project Managers also have the capability to analyse, understand and report the cost, schedule and technical performance of their project in an integrated way to project team members, executive management and other project stakeholders.

### EVM Measures and Indicators

An Earned Value Management System (EVMS) utilises three basic measures:

- Planned Values (PV), previously known as the Budgeted Cost of Work Scheduled (BCWS)
- Actual Cost (AC), previously known as the Actual Cost of Work Performed (ACWP)
- Earned Value (EV) previously known as the Budgeted Cost of Work Performed (BCWP).

Exhibit 1 provides a graphical representation of the following discussion. The time-phased sum of the cumulative Planned Values of the activities which defines the scope comprising the project produces the Performance Measurement Baseline (PMB). The sum of the projects Planned Values concludes at the Budget at Completion (BAC), the approved cost for the project. The values which form the PMB are summed at the periodic intervals (e.g., weekly or monthly) chosen to status and report on project performance. AC and EV are also accumulated on the same time phased basis and associated with the reporting periods. The time-phased sum of these values depicted graphically produces the characteristic and familiar "S-curves" as shown in Exhibit 1.

For the reader not familiar with the concept of the EV measure, the simplest way to explain the concept is to refer to a simple example where a project has a BAC of $1,000 and the percentage work complete is assessed as being 50%. The projects EV would be $500 ($1,000 x 50% complete). $500 represents the value of the actual "physical progress" accomplished by the project team as at the status date. As described by the former term, EV is measured by reference to the Budgeted Cost of Work Performed (accomplished).

From the three EVM data points the following basic project performance indicators are calculated by reference to the Earned Value measure:

- Cost Variance (CV); CV = EV – AC and Cost Performance Index (CPI); CPI = EV / AC
- Schedule Variance (SV), SV = EV – PV, and Schedule Performance Index (SPI); SPI = EV / PV.

The basics of EVM are well and comprehensively documented in many public domain sources, including as illustrative rather than comprehensive examples, Lipke (Lipke, 2003), Fleming and Koppelman (Fleming and Koppelman, 2000), Christensen (Christensen, 1998 and 1999) and Stratton (Stratton, 2006) to which the reader is directed for a more complete coverage of the topic. Stratton also includes a section on Earned Schedule, the first known EVM text book to treat ES.

## EVM Strengths

Since the EVM method was first published as the Cost Schedule Control System Criteria (CSCS/C) by the United States Air Force in 1967 it has become widely recognised as a very valuable project management and control tool particularly, in a historical context, for very large complex acquisition contracts. EVM uniquely integrates cost, schedule and technical performance information in a manner which provides quantitative project performance information on the current status of the project as well as providing predictive information on future cost performance based on the historic project performance achieved to date.

The application of EVM, predominantly on very large-scale United States Defense Department acquisition programs has been heavily researched over with the findings of this research summarised into the “EVM Body of Knowledge” (Fleming 1999). These research efforts typically focused on the behaviour of the EVM cost indicators and predictors. Significant research was conducted, principally by Dr David Christensen and associates in the 1990s and early 21st century, see Christensen 1993a, 1993b, 1995, 1998, 1999, 2002a and 2002b.

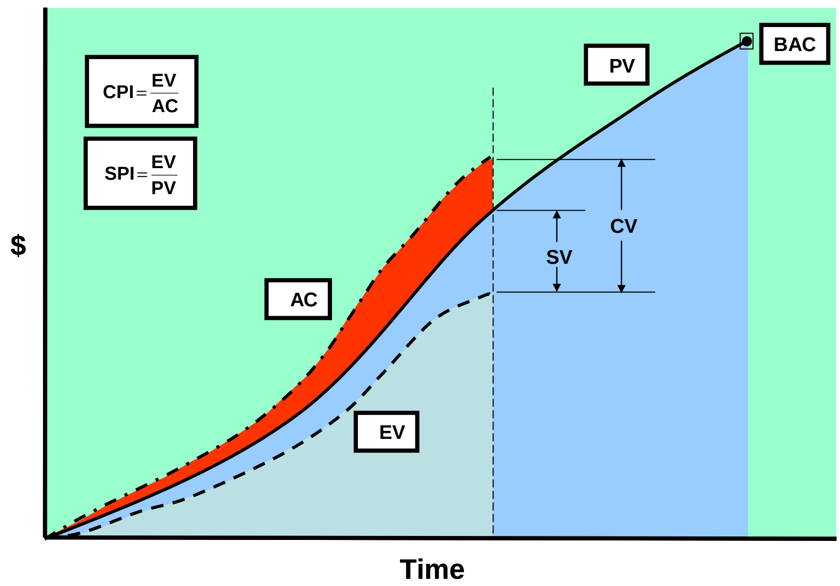


Exhibit 1 – Earned Value Basics

## EVM Limitations

While EVM has many very significant achievements in quantitatively expressing and analysing project cost performance, this success has not extended to schedule performance. Reasons for the lack of corresponding schedule success includes:

- The EVM schedule indicators are, contrary to expectation, reported in units of cost rather than time. Because cost is the unit of measure, the schedule indicators are counterintuitive and require a period of familiarization before EVM users and project stakeholders become familiar with them.
- Because EVM schedule indicators are expressed in units of cost, comparison with the time based network schedule indicators (e.g. the critical path (CP) calculated end date) is very difficult
- The much more serious issue whereby the EVM schedule indicators always return to unity at project completion. The EV always equals the final PV, the BAC. Therefore the SV always returns to zero and SPI always returns to one irrespective of duration based project delay. The schedule indicators also fail for projects which continue to execute beyond the planned completion date.

Over time EVM practice and research efforts have focused primarily on cost because these “quirks of algebra” with the EVM schedule indicators are well known and understood by experienced EVM practitioners. While the schedule indicators are available, they are not relied upon to the same extent as the indicators for cost. The resultant project management impact from the behaviour of the EVM schedule indicator issues is that cost and schedule analyses of project status and performance have become disconnected. Cost analysts view the EVM cost reports and indicators while schedulers update and analyse the network schedule. For large projects and programs, these separate skills may be segregated and the respective analyses not reconciled.

It has been a long expressed desire by EVM practitioners to have the ability to perform schedule analysis and prediction from EVM data in a similar manner to cost. Various approaches to using EVM data for this analysis have been proposed and studied from time to time. Anbari (Anbari 2003) provides a summary of those "pre ES" techniques of using EVM data for schedule analysis. However, none of those methods have proven to be satisfactory for both early and late finishing projects. Another recent method, also first published in the March 2003 edition of the Measurable News is now known as "Earned Duration", proposed by Jacob (Jacob, 2003).

## Earned Schedule Concept

Lipke conceived the ES concept during 2002 and published the ES seminal paper "Schedule is Different" (Lipke 2003) in the March 2003 edition of the PMI College of Performance Management journal, The Measurable News.

As described by Lipke in the seminal paper (Lipke 2003, p12):

> 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 BCWP earned to the performance baseline, BCWS. The time associated with BCWP, i.e. Earned Schedule, is found from the BCWS S-curve.

An alternative explanation is that the ES idea is to identify the time at which the amount of EV accrued should have been earned. By determining this time, time-based indicators can be formed to provide schedule variance and performance efficiency management information. Lipke also explicitly acknowledged:

> This concept of projecting BCWP onto BCWS is not truly new. It is illustrated in many books dealing with EVM (including Mr. Fleming's book) (Fleming and Koppelman, 2000, pp138-140).

Fleming and Koppelman and Anbari (Anbari, 2003) also make it clear that the concept of predicting a projects time duration using EVM data is not new. What is new is that while the ES measure could continue to be determined graphically as per the previous practice, "the concept becomes much more useful when facilitated as a calculation".

Exhibit 2, The Earned Schedule Concept, illustrates how the ES measure is obtained as a calculation.

As expressed in its simplest non technical form by Stratton (Stratton 2005, p3):

> Earned Schedule (ES) is the point in time when the current Earned Value was to be accomplished.

As described by Lipke in the seminal paper (Lipke 2003, p12):

> More explicitly, Earned Schedule (ES) is computed as illustrated by Figure 4 [Exhibit 2]. The cumulative value of ES is found by using BCWP to identify in which time increment of BCWS 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 BCWP extending into the incomplete time increment divided by the total BCWS planned for that same time period.

Expressed algebraically, ES cum is the number of completed PV time increments EV exceeds PV plus the fraction of the incomplete PV increment in the unit of time (i.e. weekly or monthly) being utilised.

Therefore ES cum = C + I where:

C = number of time increments where EV exceeds PV; and

$I = (EV – PV_C) / (PV_{C+1} – PV_C)$

Since ES is calculated cumulatively, periodic ES is calculated by simply subtracting the current period ES cumulative (cum) by the preceding period:

ES period(n) = EScum(n) – EScum(n-1)

From the foregoing it can be seen that:

- The incremental portion (I) only of the ES cum amount is calculated using a linear interpolation; and

- By definition, the incremental portion (I) will always be a fractional amount which will be >= 0 and < 1.

Actual Time cum (AT) is the elapsed time which has been expended since the start of the project. AT period is normally equal to 1, being:

ATperiod(n) = ATcum(n) – ATcum(n-1)

Continuing with Lipke's definitions, (Lipke 2003, p12):

> 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, of course, 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.

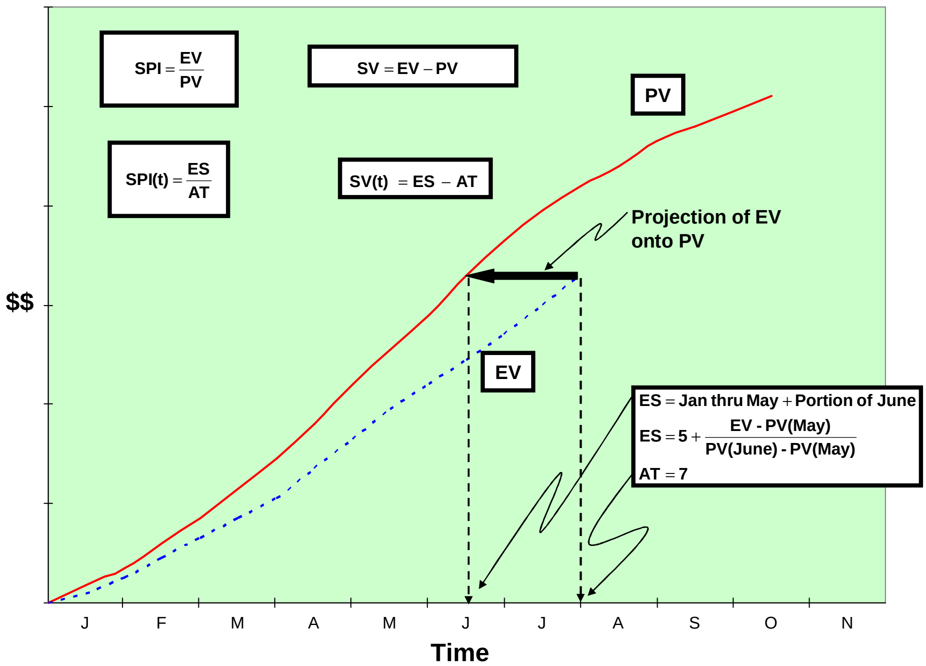


Exhibit 2 – The Earned Schedule Concept

## Earned Schedule Evolution

### Retrospective Studies Using Real Project Data

The initial paper was followed by the complimentary paper by Henderson, (Henderson 2003). Using EVM data from several completed real information technology projects, this paper independently verified that the ES measure and its derivative SV(t), and SPI(t) (denoted with (t) suffixes) functioned as described in Lipke's seminal paper.
The behaviour of the ES measure and indicators has been verified and placed in the public domain many times by practitioners using real project data from various types of projects. The findings of Vanhouke and Vandevoorde

have been published in the respected academic journals, the International Journal of Project Management (IJPM), and Journal of Operations Research (JORS), (Vanhouke & Vandevoorde 2006a and 2006b).

As an illustrative example, Exhibit 3 compares the behaviour of the traditional EVM Schedule Variance (denoted with ($) suffixes) to the behaviour of the ES SV(t) on the second y axis in a "real project" late finish example. SV(t) correctly shows the week on week schedule delay experienced by this project as a result of a "stop work" status from weeks 19 to 26 and correctly display the -14 week schedule delay experienced at project completion.

This example also illustrates the breakdown of the predictive utility of SV($) (and SPI(t)) after the planned project completion in week 20 was exceeded. SV($) "straight-lined" as the:

- Project remained at around 80% complete until the stop work was resolved in week 26; and
- No further PV on the PMB was available after the planned completion date (and BAC) was exceeded.

After the dependencies causing the stop work situation were resolved in week 26 SV($) commenced the inevitable return to zero at project completion, in spite of the extensive period of duration based schedule delay actually experienced.

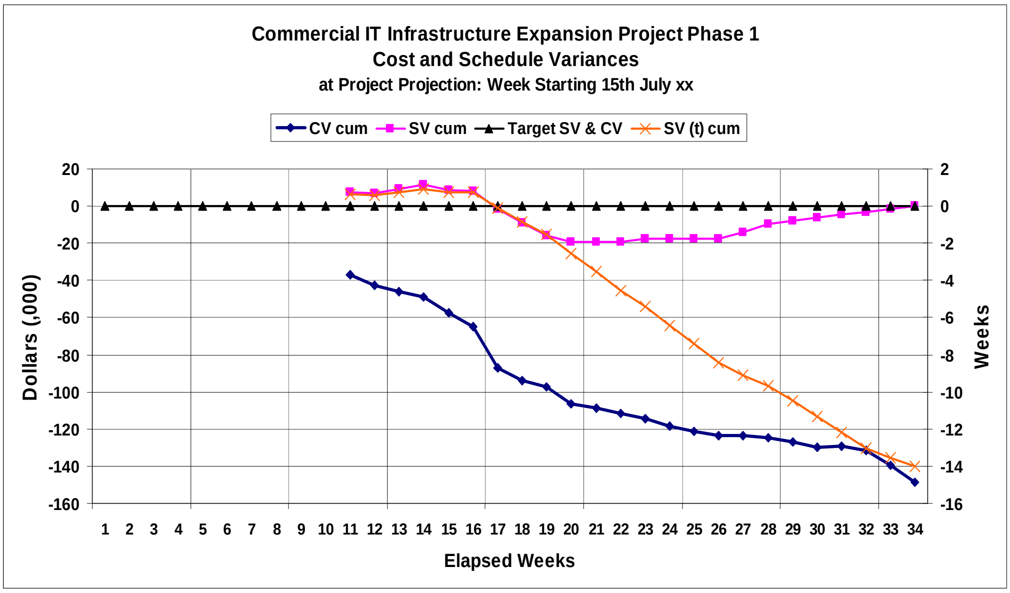


Exhibit 3 – "Late Finish" Project Cost and Schedule Variances

Exhibit 4 provides an illustrative example of an early finish project example where the behaviour of SV($) and SV(t) were closely correlated over the life of the project, including a 3 week stop work period which occurred from weeks 16 to 19.

It was concluded that the ES indicators, SV(t) and SPI(t) had greater management utility in portraying and analysing actual schedule performance compared to the traditional EVM schedule indicators.

## Outcome Prediction

Henderson (Henderson 2003) also identified a schedule duration predictor (suggested but not developed by Lipke in the seminal paper) analogous to the EVM cost predictor (known as the Independent Estimate at Complete (IEAC)) for final cost, BAC / CPI.

The "short form" schedule predictor, IEAC(t) is PD / SPI(t), where PD is the planned duration of the project. An Independent Estimate of the Completion Date (IECD) formula where IECD = Project Start Date + IEAC(t) was also developed. These formulas were applied to real project data and demonstrated the potential for project duration and completion date prediction using ES.

Henderson (Henderson, 2004) collaboratively further developed the ES formulae for outcome prediction by developing a "long form" formula, which mimics the similar equation for forecasting final cost: IEAC = AC + (BAC – EV) / PF, where PF is a selected cost performance factor. The long form schedule duration equation is

IEAC(t) = AT + (PD – ES) / PF(t), where AT is the Actual Time, PD is the Planned Duration and PF(t) is a selected time performance factor.

Henderson (Henderson 2004) also compared the outcomes predicted using the ES "short form" formula and the "pre-ES" outcome prediction techniques using EVM data described by Anbari (Anbari 2003) using real project data. This analysis demonstrated that only the ES outcome prediction techniques produced algebraically correct results and which also mimicked the behaviour of the EVM cost predictors.

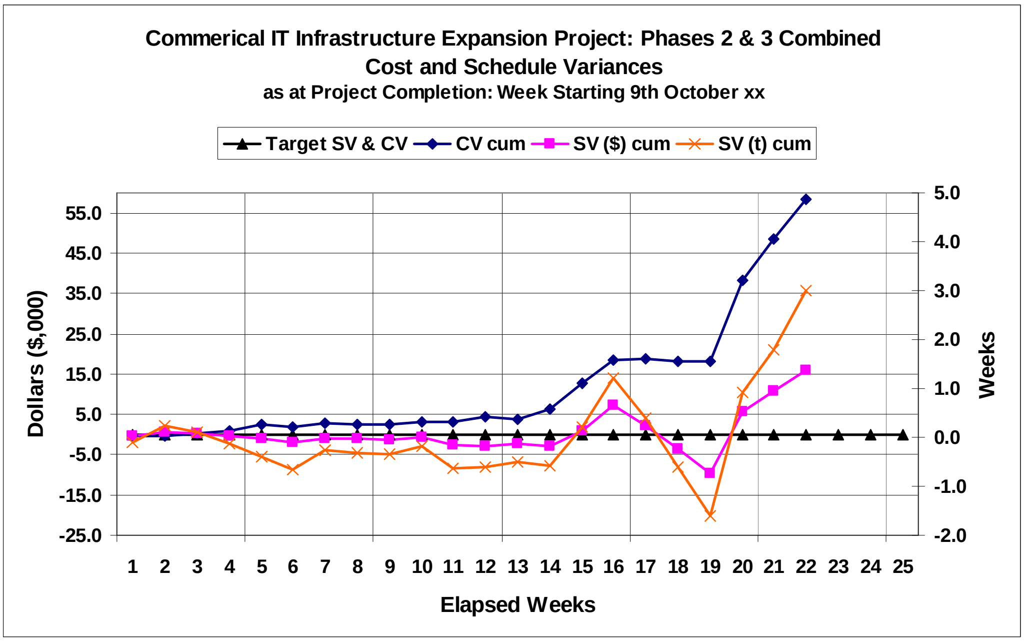


Exhibit 4 – "Early Finish" Project Cost and Schedule Variances

## Earned Schedule Application

Since the Earned Schedule seminal paper was first published by Lipke in 2003 very significant levels of interest in and adoption of the ES methodology has occurred. The Project Management Institute - College of Performance Management (PMI-CPM) interest in the new practice resulted in an "emerging practice" insert, which cited the principles of ES being included in the 2004 release of the PMI-CPM Practice Standard for Earned Value Management (PMI 2004).

Significant publicised applications of ES in the United States include:

- United States Air Force Acquisition Integration (SAF/AQX) in acquisition oversight
- Boeing Dreamliner®
- Lockheed Martin [1].

Known application in other countries include

- Two major United Kingdom Ministry of Defence programs applying ES include the Nimrod MRA4 (maritime patrol aircraft), see Higgins 2006 and Type 45 destroyer programs.
- Several smaller applications, many IT related projects, have occurred in Belgium by Fabricom Airport Systems, as well as others in Australia and the USA.

### ES Terminology

As interest in and the application of ES grew, the need for a common set of terminology was recognized. The principals and interested parties agreed to a recommendation from a meeting held at the PMI-CPM Conference in 2004 that the ES terms should be parallel to, but readily distinguishable from the EVM terms. This was thought to encourage the application of ES by minimising the learning curve required by existing EVM and new practitioners alike. As shown in exhibit 5, the chosen terms are readily comparable to the EVM counterpart. In most cases, the ES term is the analogous EVM term appended by the suffix "(t)" for "time".

## Available Earned Schedule Resources

ES information is available and readily accessible to assist current and potential users of the technique. The published papers, conference presentations and workshop materials are available from two websites:

- www.earnedschedule.com (which is expected to become the primary reference point over time) and
- http://sydney.pmichapters-australia.org.au/ (click Education, then Papers and Presentations).

The materials on both sites are freely available for download. In addition, free Excel based calculators which facilitate the application of ES are also available from the 'www.earnedschedule.com' site.

| | EVM | Earned Schedule |
|---|---|---|
| Status | Earned Value (EV) | Earned Schedule (ES) |
| | Actual Costs (AC) | Actual Time (AT) |
| | SV | SV(t) |
| | 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) |
| | Estimate at Completion (EAC) (supplier) | Estimate at Completion (time) EAC(t) (supplier) |
| | Independent EAC (IEAC) (customer) | Independent EAC (time) IEAC(t) (customer) |
| | To Complete Performance Index (TCPI) | To Complete Schedule Performance Index (TSPI) |

Exhibit 5 – "Earned Schedule Terminology

## The Way Forward

Following on from the already significant levels of global interest in the ES method, follow-on papers have resulted in additional potential advances to project management theory and practice derivable from EVM and ES. Some of these papers are theoretical and academically oriented while others are practical and practitioner oriented.

### Earned Schedule in Action

Henderson (Henderson 2005) compared the schedule outcome predictions obtained from critical path schedule analysis and the predictions obtained using the ES IEAC(t) and IECD on a small scale but time critical IT software development and enhancement project. Some of the many advantage of using ES in conjunction with critical path analysis became obvious during this project including:

- The predictions obtained from ES calculations requires considerably less effort than critical path analysis, which requires detailed task-level bottom-up updates to and analysis of the network schedule.
- Direct comparison (which is not possible using the traditional EVM schedule indicators) between the critical path predicted completion date and ES IECD is now possible since both metrics are duration based.

### Connecting Earned Value the Schedule

Lipke (Lipke 2004) has proposed the concept of "schedule adherence" and in an extension to ES theory proposed the "p factor" construct as a measure of both "schedule adherence" and "process discipline". Lipke has further developed the concept of "effective earned value" in which the "p factor" (a value >= 0 and < 1) is used to discount the EVM and ES metrics by work which has been performed "out of sequence" and therefore at risk of rework.

For the sophisticated project and program manager, “schedule adherence” and “effective earned value” offer possibilities for being able to:

- Obtain more accurate cost and schedule outcome predictions earlier in the project lifecycle than current practice allows
- Measure (and therefore manage) the level of “process discipline” being implemented on a project. Process discipline can be a particularly significant issue and risk factor for IT projects
- Quantitatively assess the risk of rework associated with undertaking work “out of sequence” as part of a deliberate management decision; and
- Quantitatively being able to assess the likely band of rework being undertaken on a project without needing to undertake the notoriously difficult and time consuming task of attempting to capture “actual rework” at the detailed level.

### Applying Earned Schedule to Critical Path Analysis and More

Lipke (Lipke 2006) further describes techniques which practitioners can apply to analyse the ES and critical path predictors concurrently. Lipke also stresses the importance of having an ES “drill down capability” analogous to the EVM drill capability for cost and in another theoretical development demonstrates how it is now possible, using the ES indicators and predictors, to ascertain from the EVM data that the critical path on a (notional) project has changed.

As a final point, while the papers discussed provides rationale for the position that ES “bridges” the two disciplines of EVM and network schedule analysis, as for cost, neither EVM nor ES can replace bottom-up estimation techniques. Both EVM for cost and ES for schedule provide predictive calculations, which are useful as macro methods for rapidly generating quantitative “top down” estimates and as cross-checks of the corresponding bottom-up analysis.

## What’s Next

The expectation is that the extraordinary level of interest in and application of ES will continue to expand and propagate. This will be coincident with the world-wide expansion of EVM and will undoubtedly be assisted by Lipke’s creditable decision to continue the long standing EVM public domain tradition for ES. ES is also expected to increase the appeal of EVM, particularly for “non-traditional” users of EVM such as commercial sector organisations, many of which may be primarily focused on schedule, with cost a second, albeit still important priority. ES also has potential applicability for organisations, which do not track Actual Costs for projects.

Interest in and application of ES to large-scale projects and programs is also expected to increase with the United Kingdom showing leadership in this project domain (see Higgins 2006). The recent conjecture (see Lipke and Henderson 2006) that the continued use of ES will result in demand for its inclusion in EVM tools has rapidly been realised. A free standalone ES addition to the Deltek Cobra EVM product has been developed by WST Pacific located in Adelaide, South Australia. This addition is available for free download at: http://www.evforums.net.au/forums/showthread.php?t=15 (free registration is required) [2]. The provision of ES updates by EVM tools vendors is anticipated to occur in response to the combination of market demand and vendor’s desire to maintain product leadership positions.

As the use of ES expands, it is clear that the current experience of more and more information being published, both practitioner and academically oriented, will continue to improve and mature the method leading to the rapid expansion of the “ES Body of Knowledge”. The ultimate intention is for ES to become a generally accepted addition to EVM included within EVM standards, guides, toolsets and training documents.

## Conclusion

ES was created as a simple solution to resolve the problem of the EVM schedule indicators failing for late finishing projects. The ES method requires only the PV and EV data, which is already available from projects utilising EVM.

Independent research conducted to date has already confirmed that, on average, ES provides better schedule prediction using EVM data than other published methods. Predicting project duration using ES is also much easier to calculate than doing detailed, bottoms-up critical path updates, estimation and analysis.

At very advanced levels, ES facilitates identification of tasks with possible impediments, constraints, or future rework. ES also has the potential to improve both cost and schedule prediction using EVM data.

Earned Schedule has become a powerful new dimension to integrated project performance management and practice, which has become a breakthrough in theory and application.

## Notes

1. The experiences of the Earned Schedule "early adopters" referenced was included at the 2005 International Integrated Performance Management Conference (IPMC) held at Tyson's Corner, Virginia USA. The presentation is entitled "*Earned Schedule Status Update and Early Adopter Applications Feedback*". Presentations by SAF/AQX, Lockheed Martin and Belgium are included in the presentation. Proprietary restrictions by Boeing have precluded publication of the slides on their experiences. The slide set referenced is available from: http://www.earnedschedule.com/Docs/ES%20Status%20Update%20IIPM%202005%20Lipke%20&%20Henderson.pdf

2. Contact details for the free Earned Schedule add-on for the Deltek Cobra product are: WST Pacific: contact: Mike Boulton (mboulton@wstpacific.com.au), +61 8 8150 5500.

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Note: This paper is made available on-line at a cost of $USD 30 from Science Direct at: http://www.sciencedirect.com/

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