Connecting Earned Value to the Schedule

PMI-CPM Conference
Long Beach, California
May 11-13, 2005

Walt Lipke
Tinker AFB
walter.lipke@tinker.af.mil
(405) 736-3341
Purpose

To discuss the application of *Earned Schedule* to schedule analysis and to introduce *Schedule Adherence* along with the concept of *Effective Earned Value*. 
Overview

• Introduction to *Earned Schedule*
• Application and Prediction Results
• Network Schedule Analysis
• Concept of *Effective Earned Value*
• Summary
Earned Value Basics

\[
\begin{align*}
\text{CPI} &= \frac{\text{BCWP}}{\text{ACWP}} \\
\text{SPI} &= \frac{\text{BCWP}}{\text{BCWS}}
\end{align*}
\]
So, what’s the problem?

- Traditional schedule EVM metrics are good at beginning of project
  - Show schedule performance trends
- But the metrics don’t reflect real schedule performance at end
  - Eventually, all “budget” will be earned as the work is completed, no matter how late you finish
    - SPI improves and ends up at 1.00 at end of project
    - SV improves and ends up at $0 variance at end of project
  - Traditional schedule metrics lose their predictive ability over the last third of project
    - Impacts schedule predictions, EAC predictions
- Project managers don’t understand schedule performance in terms of budget
  - Like most of us!
Earned Value
Cost and Schedule Variances

CV = BCWP - ACWP
SV = BCWP - BCWS

Note: Project completion was scheduled for Jan 02, but completed Apr 02.
Earned Value
Cost and Schedule Performance Indices

\[ CPI = \frac{BCWP}{ACWP} \]
\[ SPI = \frac{BCWP}{BCWS} \]

Note: Project completion was scheduled for Jan 02, but completed Apr 02.
Earned Schedule Concept
Earned Schedule Concept

**SPI($)** = \( \frac{BCWP}{BCWS} \)

**SV($) = BCWP - BCWS**

**SPI(t) = \( \frac{ES}{AT} \)**

**SV(t) = ES - AT**

Projection of BCWP onto BCWS

ES = All of May + Portion of June

ES = 5 + \( \frac{BCWP($) - BCWS(May)}{BCWS(June) - BCWS(May)} \)

AT = 7
Earned Schedule: The Formulae

- **ES\text{cum}** is the:
  Number of completed BCWS time increments BCWP exceeds + the fraction of the incomplete BCWS increment

- **ES\text{cum} = C + I** where:
  \( C = \) number of time increments for \( BCWP \geq BCWS \)
  \( I = \frac{BCWP - BCWS_C}{BCWS_{C+1} - BCWS_C} \)

- **ES\text{period}(n) = ES\text{cum}(n) - ES\text{cum}(n-1)**
  \( = \Delta ES_{\text{cum}} \)
Earned Schedule: The Schedule Indicators

• Schedule Variance (time):
  \[ SV(t) = ES_{cum} - AT_{cum} \]
  where \( AT = \) actual time
  \[ SV(t)_{\text{period}} = \Delta ES_{cum} - \Delta AT_{cum} \]
  normally \( \Delta AT_{cum} = 1 \)

• Schedule Performance Index (time):
  \[ SPI(t) = ES_{cum} / AT_{cum} \]
  \[ SPI(t)_{\text{period}} = \Delta ES_{cum} / \Delta AT_{cum} \]
Earned Schedule Indicators

• **Key Points:**
  – ES Indicators constructed to behave in an analogous manner to the EVM Cost Indicators, CV and CPI
  – $SV(t)$ and $SPI(t)$ are **not** constrained by BCWS calculation reference
  – $SV(t)$ and $SPI(t)$ provide **duration** based measures of schedule performance
Schedule Variance Comparison

**Early Finish Project**

**Late Finish Project**

SV($)  
SV(t)
Schedule Performance Index Comparison

Early Finish Project

Late Finish Project

SPI($)  SPI(t)
ES vs EVM Schedule Indicators

<table>
<thead>
<tr>
<th>Earned Schedule</th>
<th>Earned Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SV(t) and SPI(t) valid for entire project, including early and late finish</td>
<td>SV($) and SPI($) validity limited to early finish projects</td>
</tr>
<tr>
<td>Duration based predictive capability analogous to EVM’s cost based indicators</td>
<td>Limited prediction capability</td>
</tr>
<tr>
<td>Facilitates Cost – Schedule Management (using EVM and ES)</td>
<td>No predictive capability after planned completion date exceeded</td>
</tr>
<tr>
<td></td>
<td>EVM Management focused to Cost</td>
</tr>
</tbody>
</table>
Application Results
ES Applied to Real Project Data: Late Finish Project: SV($) and SV(t)

Commercial IT Infrastructure Expansion Project Phase 1
Cost and Schedule Variances
at Project Projection: Week Starting 15th July xx

- CV cum
- SV cum
- Target SV & CV
- SV (t) cum

Stop wk 19
Sched wk 20
Re-start wk 26

Rights Reserved
Early Finish Project: SV($) and SV(t)

Commerical IT Infrastructure Expansion Project: Phases 2 & 3 Combined
Cost and Schedule Variances
as at Project Completion: Week Starting 9th October xx

- Elapsed Weeks
- Dollars ($,000)

Target SV & CV
CV cum
SV ($) cum
SV (t) cum

Sched wk 25
Stop wk 16
Re-start wk 19
Duration Prediction
IEAC(t) Predictions using pre ES Techniques: Early and Late Finish Project Examples

**IEAC(t) Metrics at Project Completion**

<table>
<thead>
<tr>
<th>Early Finish Project</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Planned Duration (weeks)</td>
<td>25</td>
</tr>
<tr>
<td>Actual Time (weeks)</td>
<td>22</td>
</tr>
<tr>
<td>Percentage Complete cum</td>
<td>100%</td>
</tr>
<tr>
<td>CPI cum</td>
<td>2.08</td>
</tr>
<tr>
<td>SPI(t) cum</td>
<td>1.14</td>
</tr>
<tr>
<td>SPI($) cum</td>
<td>1.17</td>
</tr>
<tr>
<td>Critical Ratio cum</td>
<td>2.43</td>
</tr>
<tr>
<td>IEAC(t) PD/SPI(t) cum</td>
<td>22.0</td>
</tr>
<tr>
<td>IEAC(t) PD/SPI($) cum</td>
<td>21.4</td>
</tr>
<tr>
<td>IEAC(t) PD/CR cum</td>
<td>10.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Late Finish Project - pre ES</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Planned Duration (weeks)</td>
<td>20</td>
</tr>
<tr>
<td>Actual Time (weeks)</td>
<td>34</td>
</tr>
<tr>
<td>Percentage Complete cum</td>
<td>100%</td>
</tr>
<tr>
<td>CPI cum</td>
<td>0.52</td>
</tr>
<tr>
<td>SPI(t) cum</td>
<td>0.59</td>
</tr>
<tr>
<td>SPI($) cum</td>
<td>1.00</td>
</tr>
<tr>
<td>Critical Ratio cum</td>
<td>0.52</td>
</tr>
<tr>
<td>IEAC(t) PD/SPI(t) cum</td>
<td>34.0</td>
</tr>
<tr>
<td>IEAC(t) PD/SPI($) cum</td>
<td>20.0</td>
</tr>
<tr>
<td>IEAC(t) PD/CR cum</td>
<td>38.7</td>
</tr>
</tbody>
</table>

- In both examples, the **pre ES** predictors (in red) **fail** to correctly calculate the Actual Duration at Completion!
- The ES predictor, SPI(t) alone **correctly** calculates the Actual Duration at Completion in both cases.
IEAC(t) Predictions using ES Techniques
Weekly Plots of IEAC(t) - Late Finish Project Example

Commercial IT Infrastructure Expansion Project Phase 1
Earned Schedule, Independent Estimate At Completion (time) - IEAC(t)
as at Project Completion: Week Starting 15th July xx

Planned Schedule
Earned Schedule cum
IEAC(t) PD/SPI(t)

Actual Time (Weeks)
0  5 10 15 20 25 30 35 40
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
Duration (Weeks)

Plan Compl wk 20
Stop wk 19
Re-start wk 26
Schedule Analysis
Schedule Analysis with EVM?

• The general belief is EVM cannot be used to predict schedule duration

• Most practitioners analyze schedule from the bottom up using the networked schedule ....“It is the only way possible.”
  – Analysis of the Schedule is overwhelming
  – Critical Path is used to shorten analysis
    (CP is longest path of the schedule)

• Duration prediction using Earned Schedule provides a macro-method similar to the method for estimating Cost
  – a significant advance in practice

• But, there’s more that ES facilitates ....
Earned Schedule
Bridges EVM to “Real” Schedule

Time
PV
EV
SV(t)
BAC
PD
ES
AT

Rights Reserved
How Can This Be Used?

- **Tasks behind** – possibility of impediments or constraints can be identified
- **Tasks ahead** – a likelihood of future rework can be identified
- The identification is independent from schedule efficiency
- The identification can be automated

- **PMs can now have a schedule analysis tool connected to the EVM Data!!**
Earned Value Research
Earned Value Research

• Most research conducted since 1990
  – Result of cancellation of Navy A-12 Avenger
  – Primary researcher, Dr. David Christensen, Southern Utah University
  – Cost studies using very large DOD projects

• EVM Literature on Dr. Christensen’s website  http://www.suu.edu/faculty/christensend/ev-bib.html
Results from EV Research

• Dr. Christensen’s & associates’ findings
  – CPI stabilizes @ 20% complete
  – CPI tends to worsen as EV ⇒ BAC
  – $|\text{CPI(final)} - \text{CPI(20%)}| \leq 0.10$
  – IEAC = BAC / CPI ≤ Final Cost

  when Percent Complete is 20% ⇔ 100%
Research Discussion

- CPI tends to worsen as EV $\Rightarrow$ BAC
- $\text{IEAC} = \frac{\text{BAC}}{\text{CPI}} \leq \text{Final Cost}$
  when Percent Complete is 20% $\Leftrightarrow$ 100%
- IEAC condition must be true if CPI tendency is true
- Rationale supporting CPI tendency
  - Rework increasing as EV approaches BAC
  - Late occurring impacts from constraints/impediments
  - Lack of available EV toward end of project
- My conjecture: $\text{SPI}(t) \& \text{IEAC}(t) = \frac{\text{PD}}{\text{SPI}(t)}$ behave similarly to $\text{CPI} \& \text{IEAC} = \frac{\text{BAC}}{\text{CPI}}$
CPI & IEAC Behavior

CPI\textsuperscript{cum} versus Percent Complete

IEAC Behavior

Percent Difference (IEAC - Final Cost) / Final Cost
Concept: Effective Earned Value
Earned Schedule

Bridges EVM to "Real" Schedule

Time

ES  AT  PD

BAC

PV

EV

SV(t)

PV

EV

SV(t)

BAC

PV

EV

SV(t)
Effective Earned Value

- EV isn’t connected to task sequence
  - **Hypothesis**: Completion sequence of tasks affects performance efficiency
- Incorrect task sequencing occurs when there is …
  - Impediment or constraint
  - Poor process discipline
- Improper performance sequence may cause …
  - Overloading of constraint
  - Performance of tasks w/o complete inputs
Effective Earned Value

- Result from improper performance sequence …
  - Constraint limited output
    - Schedule lengthens
    - Cost increases while waiting (when other EV available is severely limited)
  - Rework occurs (~50%)
    - Schedule lengthens
    - Cost escalates
- Constraint problem & Rework appear late causing …
  - CPI & $SPI(t)$ to decrease as EV $\Rightarrow$ BAC
Effective Earned Value

- **Schedule Adherence** measure is used to enhance the EVM measures
  - Early warning for later cost and schedule problems
  - **Proposed Measure:** In accordance with the project plan, determine the tasks which should be completed or started for the duration associated with ES. Compare the associated PV with the EV of the tasks which directly correspond. Calculate the ratio:

\[
P = \frac{\text{Tasks (perf - corr)}}{\text{Tasks (plan)}} = \frac{\sum EV_j (\text{corresponding})}{\sum PV_j (\text{plan})}
\]

where \(\sum EV_j \leq \sum PV_j\) & \(\sum PV_j = EV\)
Effective Earned Value

• Characteristics of the P measure
  – P measure cannot exceed 1.0
    \[ 0 \leq P \leq 1.0 \]
  – At project completion P = 1.0
  – P is likely unstable until project is 20% complete \{similar to the behavior of CPI\}

• P used to compute effective earned value \{EV(e)\}
Effective Earned Value

$\sum EV_j \leftarrow PV @ ES$

EV(r) is performed at risk of creating rework
Portion colored is usable
Portion colored is unusable
Effective Earned Value

• Effective earned value is a function of EV, P, and Rework

\[ EV(e) = f(EV, P, \text{Rework}) \]

• \[ EV(e) = \left( \frac{1 + P \times R\%}{1 + R\%} \right) \times EV \]
  where \( R\% \) (Rework Percent) = fraction of EV(r) unusable / fraction of EV(r) usable \( \{ EV(r) = \Sigma PV_j - \Sigma EV_j \} \)

• \[ EV(e) = \left( \frac{P + 2}{3} \right) \times EV \]
  when \( R\% = 50\% \)
Effective Earned Value

- Effective ES is computed using EV(e) \{i.e., ES(e)\}
- Effective EV indicators are …
  - CV(e) = EV(e) – AC
  - CPI(e) = EV(e) / AC
  - SV(te) = ES(e) – AT
  - SPI(te) = ES(e) / AT
- The behavior of P may explain Dr. Christensen’s findings for CPI & IEAC
Graphs of CPI, CPI(e) & P - Factor (notional data)
Graphs of CPI & SPI(t) with the P - Factor

Index Value

Percent Complete

CPI
CPI(e)
SPI(t)
SPI(te)
P- Factor
Summary: Effective Earned Value

• Lack of adherence to the schedule causes EV to misrepresent project progress
• P indicator introduced to measure schedule adherence
• Effective EV calculable from P, R% and EV reported
• Prediction for both final cost and project duration hypothesized to be improved with Effective Earned Value
Summary

• ES derived from EVM data … only
• Indicators do not fail for late finish projects
• Schedule prediction is better than any other EVM method presently used
• Application is scalable up/down, just as is EVM

• **Facilitates bridging EVM to the schedule**

• Schedule Adherence Indicator
• Concept of Effective Earned Value
References

• “Schedule is Different,” *The Measurable News*, March & Summer 2003  [Walt Lipke]

• “Earned Schedule: A Breakthrough Extension to Earned Value Theory? A Retrospective Analysis of Real Project Data,”

• “Further Developments in Earned Schedule,”

• “Connecting Earned Value to the Schedule,” *The Measurable News*, Pending  [Walt Lipke]
Contact Information

Name: Walt Lipke
Organization: Software Division
Address: OCALC/MS
8745 Entrance Rd
Bldg 3333 Room 140
Tinker AFB, OK 73145-3312
Phone: (405) 736-3341
Fax: (405) 736-3345
Email: walter.lipke@tinker.af.mil