Earned Schedule Emerging Practice Workshop
Session 1

Instructors

Walt Lipke
waltlipke@cox.net
1 (405) 364-1594

Kym Henderson
Education Director
PMI Sydney, Australia Chapter
kym.henderson@froggy.com.au
61 414 428 537
Introductions

- Workshop Administration

Introductions

- Who are we?
- Why are we here?
- What are our expectations? and
- What are we hoping to gain from this Workshop?
Earned Schedule Workshop

Objective

To provide you the knowledge and tools necessary to enable you to apply Earned Value and **Earned Schedule** in your own project management practice

... should you decide to do so
Earned Schedule Training
Basic (Session 1)

- EVM Schedule Indicators
- Introduction to Earned Schedule
  - Concept & Metrics
  - Indicators
  - Predictors
  - Terminology
Earned Schedule Training
Basic (Session 1)

- Application of Concept
  - Analysis & Verification
  - Prediction Comparisons
- Exercise – Calculate $ES$, $SV(t)$, $SPI(t)$
- Status Update
  - Applications
  - PMI-CPM Earned Value Practice Standard
  - ES Website
Earned Schedule Training
Basic (Session 1)

- Analysis Tool Demonstration
- Re-Baseline Effects
- Critical Path Study
- Discussion
- Wrap Up – ES Basic
Earned Schedule Training
Advanced (Session 2)

- Interpolation Error
- Network Schedule Analysis
  - Impediments / Constraints
  - Rework
- EV Research
  - Schedule Adherence
Earned Schedule Training
Advanced (Session 2)

- Effective Earned Value
  - Derivation
  - Indicators
  - Prediction

- Statistical Prediction
  - Statistical Process Control
  - Planning for Risk
  - Performance Indication & Analysis
  - Outcome Prediction

- Summary - Advanced
Earned Schedule Training
Advanced (Session 2)

- Statistical Prediction
  - Statistical Process Control
  - Planning for Risk
  - Performance Indication & Analysis
  - Outcome Prediction
- Summary - Advanced
- Quiz & Discussion
- Wrap Up
Earned Schedule Training
Basic
Earned Value Management
Schedule Indicators
EVM Schedule Indicators

\[
\text{CPI} = \frac{\text{BCWP}}{\text{ACWP}}
\]

\[
\text{SPI} = \frac{\text{BCWP}}{\text{BCWS}}
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\[
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\text{BAC}
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\[
\text{SV}
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\[
\text{CV}
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EVM Schedule Indicators

- SV & SPI behaving erratically for projects behind schedule
  - SPI improves and concludes at 1.00 at end of project
  - SV improves and concludes at $0 variance at end of project
- Schedule indicators lose predictive ability over the last third of the project
EVM Schedule Indicators

- Why does this happen?
  - $SV = BCWP - BCWS$
  - $SPI = BCWP / BCWS$

- At planned completion $BCWS = BAC$
- At actual completion $BCWP = BAC$
- When actual > planned completion
  - $SV = BAC - BAC = $000$
  - $SPI = BAC / BAC = 1.00$

Regardless of lateness !!
Introduction to Earned Schedule
**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 Metrics

- **Required measures**
  - Performance Management Baseline (PMB) – the time phased planned values (BCWS) from project start to completion
  - **Earned Value** (BCWP) – the planned value which has been “earned”
  - **Actual Time** (AT) - the actual time duration from the project beginning to the time at which project status is assessed

- **All measures available from EVM**
Earned Schedule Metrics

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

- **ES\textsubscript{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}**

- **AT\text{cum}**

- **AT\text{period}(n) = AT\text{cum}(n) - AT\text{cum}(n-1) = \Delta AT\text{cum}**

  \(\Delta AT\text{cum}\) is normally equal to 1
Earned Schedule Indicators

- **Schedule Variance: SV(t)**
  - Cumulative: \( SV(t) = ES_{cum} - AT_{cum} \)
  - Period: \( \Delta SV(t) = \Delta ES_{cum} - \Delta AT_{cum} \)

- **Schedule Performance Index: SPI(t)**
  - Cumulative: \( SPI(t) = ES_{cum} / AT_{cum} \)
  - Period: \( \Delta SPI(t) = \Delta ES_{cum} / \Delta AT_{cum} \)
Earned Schedule Indicators

- What happens to the ES indicators, SV(t) & SPI(t), when the planned project duration (PD) is exceeded (BCWS = BAC)?

  **They Still Work ...Correctly!!**

- ES will be ≤ PD, while AT > PD
  - SV(t) will be negative (time behind schedule)
  - SPI(t) will be < 1.00

**Reliable Values from Start to Finish !!**
SV Comparison

- Early Finish Project
- Late Finish Project

SV($) vs. SV(t)

Early Finish Project

Late Finish Project

$ vs. Mo

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SPI Comparison

Early Finish Project

Late Finish Project

SPI($)  SPI(t)
Earned Schedule Predictors

- Can the project be completed as planned?
  - TSPI = Plan Remaining / Time Remaining
    \[ = \frac{(PD - ES)}{(PD - AT)} \]
    where (PD – ES) = PDWR
    PDWR = Planned Duration for Work Remaining
  - TSPI = (PD – ES) / (ED – AT)
    where ED = Estimated Duration

<table>
<thead>
<tr>
<th>TSPI Value</th>
<th>Predicted Outcome</th>
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<tr>
<td>( \leq 1.00 )</td>
<td>Achievable</td>
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<td>&gt; 1.10</td>
<td>Not Achievable</td>
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Earned Schedule Predictors

- Long time goal of EVM ... *Prediction of total project duration from present schedule status*

- Independent Estimate at Completion (time)
  - IEAC(t) = PD / SPI(t)
  - IEAC(t) = AT + (PD – ES) / PF(t)
    where PF(t) is the Performance Factor (time)
  - Analogous to IEAC used to predict final cost

- Independent Estimated Completion Date (IECD)
  - IECD = Start Date + IEAC(t)
# Earned Schedule Terminology

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<tr>
<th>Status</th>
<th>EVM</th>
<th>Earned Schedule</th>
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<td><strong>Earned Value (EV)</strong></td>
<td>Earned Schedule (ES)</td>
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<td><strong>Actual Costs (AC)</strong></td>
<td>Actual Time (AT)</td>
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<td><strong>Future Work</strong></td>
<td><strong>Planned Duration for Work Remaining (PDWR)</strong></td>
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<td><strong>Budgeted Cost for Work Remaining (BCWR)</strong></td>
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<td><strong>Estimate to Complete (ETC)</strong></td>
<td>Estimate to Complete (time) ETC(t)</td>
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<td><strong>Prediction</strong></td>
<td><strong>To Complete Schedule Performance Index (TCPI)</strong></td>
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<td><strong>Variance at Completion (VAC)</strong></td>
<td>Variance at Completion (time) VAC(t)</td>
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<td><strong>Estimate at Completion (EAC) (supplier)</strong></td>
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<td><strong>Independent EAC (IEAC) (customer)</strong></td>
<td>Independent EAC (time) IEAC(t) (customer)</td>
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<td><strong>To Complete Performance Index (TCPI)</strong></td>
<td>To Complete Schedule Performance Index (TSPI)</td>
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## Earned Schedule Terminology

<table>
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<tr>
<th>Metrics</th>
<th>Earned Schedule</th>
<th>$ES_{cum}$</th>
<th>Indicators</th>
<th>Predictors</th>
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<tr>
<td><strong>Actual Time</strong></td>
<td>$AT_{cum}$</td>
<td>AT = number of periods executed</td>
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<td><strong>Indicators</strong></td>
<td>$SV(t)$</td>
<td>$SV(t) = ES - AT$</td>
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<td>$SPI(t) = ES / AT$</td>
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<td>$TSPI(t) = (PD - ES) / (ED - AT)$</td>
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<td><strong>Predictors</strong></td>
<td>$IEAC(t)$</td>
<td>$IEAC(t) = PD / SPI(t)$</td>
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<td>$IEAC(t)$</td>
<td>$IEAC(t) = AT + (PD - ES) / PF(t)$</td>
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</table>

- **Earned Schedule**: $ES = C + I$, number of complete periods (C) plus an incomplete portion (I)
- **Actual Time**: $AT_{cum}$ = number of periods executed
- **Schedule Variance**: $SV(t) = ES - AT$
- **Schedule Performance Index**: $SPI(t) = ES / AT$
- **To Complete Schedule Performance Index**: $TSPI(t) = (PD - ES) / (PD - AT)$
- **Independent Estimate at Completion (time)**: $IEAC(t) = PD / SPI(t)$
- **Independent Estimate at Completion (time)**: $IEAC(t) = AT + (PD - ES) / PF(t)$
Earned Schedule Key Points

- **ES Indicators** constructed to behave in an analogous manner to the EVM Cost Indicators, CV and CPI

- **SV(t) and SPI(t)**
  - Not constrained by BCWS calculation reference
  - Provide *duration* based measures of schedule performance
  - Valid for entire project, including early and late finish

- **Facilitates integrated Cost/Schedule Management** (using EVM with ES)
Application of Concept
(Using Real Project Data)
ES Applied to Real Project Data: 
*Late Finish Project: SV($) and SV(t)*

![Graph](Image)

**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

**Cost and Schedule Variances Graph**

- **Dollars (\(\times 10^{5}\))**
- **Weeks**
- **Elapsed Weeks**

- **Weeks (1-34)**
- **Dollars (\(\times 10^{5}\))**

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ProMAC 2006 26th Sep 2006

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29
ES Applied to Real Project Data: Late Finish Project Analysis

- No EVM data prior to week 11
- SV($) and SV(t) show strong correlation until week 19
  - Week 20 (The week of the project’s scheduled completion)
    Client delay halted project progress until resolution in Week 26
- SV($) static at -$17,500 in spite of schedule delay
  - Before trending to $0 at project completion
- SV(t) correctly calculates and displays
  - Week on week schedule delay
  - Project -14 week schedule delay at completion

**Conclusion**
- SV(t) provides greater management utility than SV($) for portraying and analyzing schedule performance
## Early Finish Project: SV($) 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

<table>
<thead>
<tr>
<th>Elapsed Weeks</th>
<th>Target SV &amp; CV</th>
<th>CV cum</th>
<th>SV ($) cum</th>
<th>SV (t) cum</th>
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Stop wk 16

Re-start wk 19

Sched wk 25
Early Finish Project Analysis

- This project completed 3 weeks ahead of schedule
  - In spite of externally imposed delay between weeks 16 and 19
- SV($) and SV(t) show strong correlation over life of project
  - Including the delay period
  - SV(t)’s advantage is calculating delay as a measure of duration
- With Early Finish projects
  - ES metrics SV(t) and SPI(t) have behaved consistently with their historic EVM counterparts
- **Conclusion**
  - SV(t) provides greater management utility than SV($) for portraying and analyzing schedule performance
Prediction Comparisons
“Further Developments” in Earned Schedule

Schedule Duration Prediction

- Calculation of IEAC(t): short form
  \[ IEAC(t) = \frac{\text{Planned Duration}}{\text{SPI}(t)} \]

- Planned Duration for Work Remaining
  \[ \text{PDWR} = \text{Planned Duration} - \text{Earned Schedule cum} \]
  - Analogous to the EVM BCWR

- Calculation of IEAC(t): long form
  \[ IEAC(t) = \text{Actual Time} + \left( \frac{\text{PDWR}}{\text{Performance Factor}} \right) \]
IEAC(t) Prediction Comparison

Early and Late Finish Project Examples

### IEAC(t) Metrics at Project Completion

#### Early Finish Project

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
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<tbody>
<tr>
<td>Planned Duration (weeks)</td>
<td>25</td>
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<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>
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<tr>
<td>SPI(t) cum</td>
<td>1.14</td>
</tr>
<tr>
<td>SPI($) cum</td>
<td>1.17</td>
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<tr>
<td>Critical Ratio cum</td>
<td>2.43</td>
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<tr>
<td>IEAC(t) PD/SPI(t) cum</td>
<td>22.0</td>
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<tr>
<td>IEAC(t) PD/SPI($) cum</td>
<td>21.4</td>
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<tr>
<td>IEAC(t) PD/CR cum</td>
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#### Late Finish Project - pre ES

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<tbody>
<tr>
<td>Planned Duration (weeks)</td>
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<tr>
<td>Actual Time (weeks)</td>
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<tr>
<td>Percentage Complete cum</td>
<td>100%</td>
</tr>
<tr>
<td>CPI cum</td>
<td>0.52</td>
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<td>SPI(t) cum</td>
<td>0.59</td>
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<tr>
<td>SPI($) cum</td>
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<td>Critical Ratio cum</td>
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<tr>
<td>IEAC(t) PD/SPI(t) cum</td>
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<td>IEAC(t) PD/SPI($) cum</td>
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<td>IEAC(t) PD/ CR cum</td>
<td>38.7</td>
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</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
"Further Developments" in Earned Schedule

Schedule Duration Prediction (continued)

- Pre ES formulae and results algebraically flawed

  “...there is little theoretical justification for EVM practitioners continuing to use the pre ES predictors of schedule performance. Conversion to and use of the ES based techniques is strongly recommended.”

  - Kym Henderson

There’s got to be a better method!
IEAC(t) Predictions using ES Techniques: Same Early and Late Finish Project Examples

### Early Finish Project using ES

<table>
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<th>Metric</th>
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<tbody>
<tr>
<td>Planned Duration (weeks)</td>
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<tr>
<td>Actual Time (weeks)</td>
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<tr>
<td>Earned Schedule cum</td>
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<tr>
<td>Planned Duration Work Remaining</td>
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</tr>
<tr>
<td>Percentage Complete cum</td>
<td>100%</td>
</tr>
<tr>
<td>CPI cum</td>
<td>2.08</td>
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<td>SPI(t) cum</td>
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<td>SPI($) cum</td>
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<td>Critical Ratio cum</td>
<td>2.43</td>
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<tr>
<td>Critical Ratio ES cum</td>
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<tr>
<td>IEAC(t) PF = SPI(t) cum</td>
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<tr>
<td>IEAC(t) PF = SPI($) cum</td>
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<tr>
<td>IEAC(t) PF = CR cum</td>
<td>22.0</td>
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<tr>
<td>IEAC(t) PF = CR ES cum</td>
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### Late Finish Project using ES

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<th>Metric</th>
<th>Value</th>
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<td>Planned Duration (weeks)</td>
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<td>Actual Time (weeks)</td>
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<td>Earned Schedule cum</td>
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<tr>
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<tr>
<td>IEAC(t) PF = CR cum</td>
<td>34.0</td>
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<tr>
<td>IEAC(t) PF = CR ES cum</td>
<td>34.0</td>
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</tbody>
</table>

Use of the ES “long form” IEAC(t) formula, results in **correct** calculation of Actual Duration at Completion.

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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)

Stop wk 19
Re-start wk 26
Plan Dur wk 20

Duration (Weeks)

Actual Time (Weeks)
IECD Predictions using ES Techniques: Weekly Plots of Independent Estimate of Completion Date

Commercial IT Infrastructure Expansion Project Phase 1
Earned Schedule, Independent Estimates of Completion Date (IECD)
as at Project Completion: Week Starting 15th July xx

- Planned Schedule
- Earned Schedule cum
- Planned Completion Date
- Independent Estimate of Completion Date

Actual Time (Weeks)
Duration (Weeks)

Stop wk 19
Plan Dur wk 20
Compl Apr 7
Re-start wk 26
“Further Developments” in Earned Schedule

Schedule Duration Prediction (continued)

- Pre ES formulae and results algebraically flawed

“... there is little theoretical justification for EVM practitioners continuing to use the pre ES predictors of schedule performance. Conversion to and use of the ES based techniques is strongly recommended.”

- Kym Henderson

There’s got to be a better method!
2 My Experience Summarised

- **Schedule Performance Indicators** (for early and late finish projects):
  - SPI(t) & SV(t) do portray the real schedule performance in agreement with [1] [2]
- **Forecasting Duration** (for early and late finish projects):
  - at early & middle project stage: pre-ES & ES forecasts produce similar results at late project stage: ES forecasts outperform all pre-ES forecasts in agreement with [2] [3]
- **Assessing Project Duration** (for early and late finish projects):
  - the use of the SPI(t) in conjunction with the TCSPI(t) has been demonstrated to be useful to manage the schedule expectations application of [3]

Exercise – Calculate $ES, SV(t), SPI(t)$
Exercise # 1

- Complete Early & Late Worksheets (tan areas only):
  - \( ES, SV(t), SPI(t) \)

- Earned Schedule Formulas:
  - \( ES = \text{Nr of Completed BCWS Time Periods} \)
    + Fraction of Uncompleted Period
  - Fraction = \( (BCWP - BCWS_n) / (BCWS_{n+1} - BCWS_n) \)
  - \( AT = \text{Actual Time (number of periods from start)} \)
  - Schedule Variance: \( SV(t) = ES - AT \)
  - Schedule Performance Index: \( SPI(t) = ES / AT \)
## ES Exercise - Worksheet

<table>
<thead>
<tr>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
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### Early Finish Project (Cumulative Values)
## ES Exercise - Worksheet

### Late Finish Project (Cumulative Values)

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### Late Finish Project (Cumulative Values)

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ProMAC 2006 26th Sep 2006
## ES Exercise - Answers

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## Early Finish Project (Cumulative Values)

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## ES Exercise - Answers

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## Late Finish Project (Cumulative Values)
Status Update
Early Adopters

- EVM Instructors
  - PMA, Management Technologies ...
- Boeing Dreamliner®, Lockheed Martin, US State Department, Secretary of the Air Force
- UK MoD – Nimrod, Type 45 Destroyer
- Several Countries - Australia, Belgium, Sweden, UK, USA ...
- Applications across weapons programs, construction, software development, ...
- Range of project size from very small and short to extremely large and long duration
“Time-Based Schedule Measures -- An Emerging EVM Practice”

Part of the EVM Practice Standard

- Included in Box 3-1 of EVM Practice Standard
  - Describes basic principles of “Earned Schedule”
  - Provides foundation for further development of and research intended to result in Earned Schedule acceptance as a valid extension to EVM

- EVM Practice Standard being released at this Conference (November 2004)
Available Resources

  - Repository for ES Papers and Presentations

  - Established February 2006
  - Contains *News, Papers, Presentations, ES Terminology, ES Calculators*
  - Identifies Contacts to assist with application

Foreseen Uses of Earned Schedule

- Enables independent evaluation of schedule estimates: ETC(t), EAC(t)
  - Client, Contractor, Program and Project Manager ....
- Facilitates insight into network schedule performance
  - Duration based Schedule indicators
  - Identification of impediments/constraints and potential future rework
  - Evaluation of adherence to plan
- Improvement to Schedule and Cost prediction
  - Client, Contractor, Program and Project Manager ....
- Application of direct statistical analysis of schedule performance
Extracted results from [8]: Forecast Accuracy and the Completion of Work

Simulation runs performed: 1 run project finish ahead of schedule, 1 run projects finish behind schedule.

Plants are made to present the research report “A simulation and evaluation of earned value metrics to forecast the project duration” at the 22nd PMI-CPM Spring Conference 2006.

Demonstration of Earned Schedule Calculator
Earned Schedule Calculator

Earned Schedule Calculator (V1)
Earned Schedule Calculator (V2)
Demonstration of Earned Schedule Analysis Tool
Earned Schedule Analysis Tool
ES and Re-Baselining
ES and Re-Baselining

- ES indicators are affected by re-baselining
  - Behaviour of SV(t) and SPI(t) is analogous to CV and CPI
    - See examples
- PMB change affects schedule prediction similarly to cost
- Earned Schedule brings attention to the potential schedule impact of a declared “cost only” change


1. Nominal Re-plan 02 July
Cost and schedule overrun

2. Schedule delay

3. Re-baseline effect

---

**Actual Time (weeks)**

<table>
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<tr>
<th></th>
<th>01 Jan</th>
<th>29 Jan</th>
<th>26 Feb</th>
<th>26 Mar</th>
<th>30 Apr</th>
<th>28 May</th>
<th>25 Jun</th>
<th>02 Jul</th>
<th>30 Jul</th>
<th>27 Aug</th>
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<tr>
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<td>0.00</td>
<td>4.00</td>
<td>8.00</td>
<td>12.00</td>
<td>17.00</td>
<td>21.00</td>
<td>25.00</td>
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<td>19.11</td>
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<td>33.12</td>
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</tbody>
</table>

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**Real project data**

**Nominal re-baseline**
### Earned Schedule – Re-Baseline Example

**CV, SV($) and SV(t)**

#### 1. Nominal Re-plan 02 July
Cost and schedule overrun

#### 2. Cost Overrun

#### 3. Schedule delay

#### 4. “Sawtooth” effect of re-baselining (CV, SV($) and SV(t)

<table>
<thead>
<tr>
<th>Actual Time (weeks)</th>
<th>01 Jan</th>
<th>29 Jan</th>
<th>26 Feb</th>
<th>26 Mar</th>
<th>30 Apr</th>
<th>28 May</th>
<th>25 Jun</th>
<th>02 Jul</th>
<th>30 Jul</th>
<th>27 Aug</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV cum</td>
<td>0.00</td>
<td>(12.14)</td>
<td>(23.70)</td>
<td>(42.92)</td>
<td>(87.31)</td>
<td>(108.61)</td>
<td>(121.43)</td>
<td>6.90</td>
<td>11.09</td>
<td>(2.30)</td>
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<tr>
<td>SV($) cum</td>
<td>0.00</td>
<td>(0.41)</td>
<td>6.65</td>
<td>6.73</td>
<td>(1.42)</td>
<td>(22.07)</td>
<td>(46.48)</td>
<td>(8.60)</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>SV(t) cum</td>
<td>0.00</td>
<td>(0.16)</td>
<td>0.60</td>
<td>0.56</td>
<td>(0.13)</td>
<td>(3.55)</td>
<td>(7.41)</td>
<td>(0.09)</td>
<td>(1.30)</td>
<td>(1.00)</td>
</tr>
</tbody>
</table>

#### 5. 1 week completion delay on re-baselined PMB
Critical Path Study
Critical Path Study Outline

- The Scheduling Challenge
- Case Study Project
  - The project
  - The EVM, Earned Schedule and Network Schedule approach
- Earned Schedule vs Critical Path predictors
- Real Schedule Management with Earned Schedule
  - Initial experience and observation
A realistic project schedule is dependent on multiple, often complex factors including accurate:

- Estimation of the tasks required,
- Estimates of the task durations
- Resources required to complete the identified tasks

Identification and modeling of dependencies impacting the execution of the project

- Task dependencies (e.g. F-S process flows)
- “Dependent” Milestones (internal and external)
- “Other logic”
The Scheduling Challenge

- From small projects into large projects and programs, scheduling requirements becomes exponentially more complex

- Integration
  - Of schedules between “master” and “subordinate” schedules
  - Often across multiple tiers of
    - Activities and
    - Organisations
  
- Essential for producing a useful integrated master schedule
To further compound schedule complexity

Once an initial schedule baseline has been established progress monitoring inevitably results in changes

- Task and activity durations change because “actual performance” does not conform to plan
- Additional unforeseen activities may need to be added
- Logic changes as a result of corrective actions to contain slippages; and
- Improved understanding of the work being undertaken
- Other “planned changes” (Change Requests) also contribute to schedule modifications over time
Wouldn’t it be nice ....

- To be able to explicitly declare “Schedule Reserve” in the project “schedule of record”
  - Protect committed key milestone delivery dates

- To have schedule macro level indicators and predictors
  - Ideally, derived separately from the network schedule!
  - Provides a means for comparison and validation of the measures and predictors provided by the network schedule
  - An independent predictor of project duration would be a particularly useful metric
    - “On time” completion of projects usually considered important

- Just like EVM practitioners have for cost ....
  - The potential offered by Earned Schedule
Case Study Project

- Commercial sector software development and enhancement project
  - Small scale: 10 week Planned Duration
  - Time critical: Needed to support launch of revenue generating marketing campaign
  - Cost budget: 100% labour costs

- Mixture of:
  - 3 tier client server development
    - Mainframe, Middleware, Workstation
  - 2 tier client server development
    - Mainframe to Workstation direct
The EVM and ES Approach

- Microsoft Project 2002 schedule
  - Resource loaded for time phased effort and cost estimation
  - Control Account – Work Package views developed in the schedule
  - Actual Costs captured in SAP time recording system
    - Limited (actual) cost – schedule integration
  - Contingency (Management Reserve) managed outside the schedule
  - Top level Planned Values cum “copied and pasted” into Excel EVM and ES template
    - High level of cost – schedule integration achieved
Schedule Management

- Weekly schedule updates from week 3 focusing on:
  - Accurate task level percentage work completion updates
  - The project level percentage work completion (cumulative) calculated by Microsoft Project
    - Percentage work complete transferred to the EVM and ES template to derive the progressive Earned Value (cumulative) measure

- Schedule review focusing on critical path analysis
  - Schedule updates occurred as needed with
  - Revised estimates of task duration and
  - Changes to network schedule logic particularly when needed to facilitate schedule based corrective action

- Actual costs entered into the EVM and ES template as they became available (weekly)
An Integrated Schedule Analysis Chart
Critical Path, IECD, SPI(t) and SPI($) on one page

![Graph showing various schedule analysis metrics such as Planned Complete for Date, ECD/PC, SPI(t), SPI($), and Critical Path Completion for different dates including 01 Aug, 11 Aug, 21 Aug, 31 Aug, 10 Sep, 20 Sep, and 30 Sep. The graph includes a legend with different symbols and colors representing each metric. The x-axis represents the duration in weeks, starting from 01 Aug to 10 Oct, and the y-axis represents SPI($) values ranging from 0.4 to 1.8.]
Schedule Analysis

- **Initial expectation**
  - The critical path predicted completion date would be more pessimistic than the IECD

- **In fact**
  - The ES IECD trend line depicted a “late finish” project with improving schedule performance
  - The critical path predicted completion dates showed an “early finish project” with deteriorating schedule performance

- **Became the “critical question” in Week 8**
  - ES IECD improvement trend reversed
  - Continued deterioration in the critical path predicted completion dates
Schedule Analysis Result

- IECD the more credible predictor in this circumstance
  - Work was not being accomplished at the rate planned
  - No adverse contribution by critical path factors
    - e.g. Externally imposed delays caused by “dependent milestone”
- Two weeks schedule delay communicated to management
  - Very late delay of schedule slippage a very sensitive issue
- Corrective action was immediately implemented
  - Resulted in two weeks progress in one week based on IECD improvement in week 9
  - Project substantively delivered to the revised delivery date
The IECD vs Critical Path Predictors

- Network schedule updates do not usually factor past (critical path) task performance into the future
  - Generally concentrate on the current time window
    - Task updates
    - Corrective action to try and contain slippages
  - Critical path predicted completion date is not usually calibrated by past actual schedule performance

- The ES IECD
  - Cannot directly take into account critical path information
  - BUT does calibrate the prediction based on historic schedule performance as reflected in the SPI(t)
Further Observations

- Much has been written about the consequences of not achieving work at the EVM rate planned
  - At very least, incomplete work needs to be rescheduled ...
  - Immediate critical vs non critical path implication requires detailed analysis of the network schedule
- Sustained improvement in schedule performance is a difficult challenge
  - SPI(t) remained in the .7 to .8 band for the entire project!
  - In spite of the corrective action and recovery effort
- Any task delayed eventually becomes critical path if not completed
- SPI(t) a very useful indicator of schedule performance
  - Especially later in the project when SPI($) was resolving to 1.0
Questions of Scale

- We know that ES is scalable as is EVM
  - Issues of scale did not arise due to small size of the project
- Detailed analysis of the ES metrics is required
  - The same as EVM for cost
  - The “masking” or “washout” effect of negative and positive ES variances at the detailed level can be an issue
  - The same as EVM for cost
- Apply Earned Schedule to the Control Accounts and Work Packages on the critical path
  - And “near” critical path activities
- Earned Schedule augments network schedule analysis – it doesn’t replace it
  - Just as EVM doesn't replace a bottom up ETC and EAC
Real Schedule Management with Earned Schedule

- ES is of considerable benefit in analysing and managing schedule performance
- The “time critical” dichotomy of reporting “optimistic” predicted task completions and setting and reporting realistic completion dates was avoided
  - ES metrics provided an independent means of sanity checking the critical path predicted completion date
  - Prior to communicating overall schedule status to management
- ES focused much more attention onto the network schedule than using EVM alone
Final Thoughts

- ES is expected be of considerable value to the schedule management for large scale projects and programs
  - Exponential increase in the network scheduling complexities
  - Unavoidable and necessary on those programs and so
  - The need and benefit of an independent means of sanity checking schedules of such complexity is much greater
- ES is anticipated to become the “bridge” between EVM and the Network Schedule
Summary - Basic
Summary - Basic

- Derived from EVM data ... only
- Provides time-based schedule indicators
- Indicators do not fail for late finish projects
- Application is scalable up/down, just as is EVM
- Schedule prediction is better than any other EVM method presently used
  - SPI(t) behaves similarly to CPI
  - IEAC(t) = PD / SPI(t) behaves similarly to IEAC = BAC / CPI
Summary - Basic

- Schedule prediction – much easier and possibly better than “bottoms-up” schedule analysis
- Application is growing in both small and large projects
- Practice recognized as “Emerging Practice”
- Resource availability enhanced with ES website and Wikipedia
- Research indicates ES superior to other methods
Earned Schedule Training

Basic

- Discussion
- Wrap Up – ES Basic
Earned Schedule Emerging Practice Workshop
Session 2

Instructors

Walt Lipke
waltlipke@cox.net
1 (405) 364-1594

Kym Henderson
Education Director
PMI Sydney, Australia Chapter
kym.henderson@froggy.com.au
61  414 428 537
Earned Schedule Training
Basic (Session 1)

- EVM Schedule Indicators
- Introduction to Earned Schedule
  - Concept & Metrics
  - Indicators
  - Predictors
  - Terminology
Earned Schedule Training
Basic (Session 1)

- Application of Concept
  - Analysis & Verification
  - Prediction Comparisons

- Exercise – Calculate $ES$, $SV(t)$, $SPI(t)$

- Status Update
  - Applications
  - PMI-CPM Earned Value Practice Standard
  - ES Website
Earned Schedule Training
Basic (Session 1)

- Analysis Tool Demonstration
- Re-Baseline Effects
- Critical Path Study
- Discussion
- Wrap Up – ES Basic
Earned Schedule Training Advanced (Session 2)

- Interpolation Error
- Network Schedule Analysis
  - Impediments / Constraints
  - Rework
- EV Research
  - Schedule Adherence
Earned Schedule Training
Advanced (Session 2)

- Effective Earned Value
  - Derivation
  - Indicators
  - Prediction

- Statistical Prediction
  - Statistical Process Control
  - Planning for Risk
  - Performance Indication & Analysis
  - Outcome Prediction

- Summary - Advanced
Earned Schedule Training
Advanced (Session 2)

- Statistical Prediction
  - Statistical Process Control
  - Planning for Risk
  - Performance Indication & Analysis
  - Outcome Prediction
- Summary - Advanced
- Quiz & Discussion
- Wrap Up
Earned Schedule Training
Advanced
Interpolation Error
Interpolation Error

- The PMB is an S-Curve. Does the linear interpolation introduce large ES error?
- Is error larger where the S-Curve is steepest?
- What affects the accuracy of the ES calculation?
Interpolation Error

\[ I_{/1 \text{ mo}} = \frac{p}{q} \]

\[ I = \left( \frac{p}{q} \right) \times 1 \text{ mo} \]

\[ p = \text{BCWP} - \text{BCWS}_C \]
\[ q = \text{BCWS}_{C+1} - \text{BCWS}_C \]

\[ I = \frac{\text{BCWP} - \text{BCWS}_C}{\text{BCWS}_{C+1} - \text{BCWS}_C} \times \text{1mo} \]
Interpolation Error

\[ \text{ES} = \text{Number of whole months (C)} + \text{Increment on curve (F)} = C + F \]

\[ \text{ES(calc)} = C + \text{calculated increment (I)} \]

\[ \text{Error} (\delta) = I - F \]

\[ \% \text{error} = \frac{|\delta|}{C + F} \]

Example = \(0.05 / 8.12 = 0.6\%\)

As \(C\) \(\Rightarrow\) larger
- \% error \(\Rightarrow\) smaller
- \(\text{ES(calc)}\) \(\Rightarrow\) more accurate

Weekly EV make ES more accurate
Interpolation Error

- After a few months of status $C > 4$ - interpolation error is negligible ($\leq 3\%$)

- What about central portion of PMB, where $S$-Curve is steepest? Is error greater?
  - Where slope is large, the resolution of the interpolation is maximized
  - Curvature of PMB is minimized
  - Interpolation error is negligible
Other Sources of Error

- Partial Month – 1st month
  - Much more significant than interpolation error
  - Error decreases as C becomes larger
  - Correctable – adjust calculator output

- Earned Value recorded
  - By far, the largest source of ES error
  - Low accuracy for EV \Rightarrow\ inaccurate ES
Network 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\)
Schedule Analysis with EVM?

- 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*

- **PV**: Planned Value
- **EV**: Earned Value
- **SV(t)**: Schedule Variance

**Time**

- **ES**: Earned Start
- **AT**: Actual Time
- **PD**: Planned End

**BAC**: Budget at Completion
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](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 $\Rightarrow$ BAC
  - $|\text{CPI(final)} - \text{CPI(20\%)}| \leq 0.10$
  - IEAC = BAC / CPI $\leq$ Final Cost

\[ \text{when Percent Complete is 20\% } \Leftrightarrow \text{ 70\%} \]
Discussion of EV Research

- CPI tends to worsen as EV $\Rightarrow$ BAC
- IEAC = BAC / CPI $\leq$ Final Cost
  
  when Percent Complete is $\geq$ 20%

- **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: SPI(t) & IEAC(t) = PD / SPI(t) behave similarly to CPI & IEAC = BAC / CPI*
CPI & IEAC Behavior

CPIcum versus
Percent Complete

IEAC Behavior

Percent Difference
(IEAC - Final Cost) / Final Cost

Percent Complete

Percent Complete
Schedule Adherence
Schedule Adherence

- 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
Schedule Adherence

- 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 ⇒ BAC**
Schedule Adherence

- 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:*

  \[
P = \frac{\text{Tasks (perf - corr)}}{\text{Tasks (plan)}} = \frac{\sum \text{EV}_j \ (\text{corresponding})}{\sum \text{PV}_j \ (\text{plan})}
\]

  where \( \sum \text{EV}_j \leq \sum \text{PV}_j \) & \( \sum \text{PV}_j = \text{EV} \)
Schedule Adherence

- 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)
  - The behavior of P may explain Dr. Christensen’s findings for CPI & IEAC
  - P used to compute effective earned value \{EV(e)\}
Effective Earned Value
Effective Earned Value

$\Sigma EV_j \leftarrow PV @ ES$

Effective EV

Total EV

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

- P-Factor (or P) = \( \Sigma EV_j / \Sigma PV_j = \Sigma EV_j / EV \)
  \[ \Sigma EV_j = P \times EV \]

- EV(p) is portion of EV consistent with the plan
  \[ EV(p) = \Sigma EV_j = P \times EV \]

- EV(r) is portion of EV with anticipated rework
  \[ EV(r) = EV - EV(p) = EV - P \times EV \]
  \[ EV(r) = (1 - P) \times EV \]
Effective EV Relationships

- Rework proportion (R%) = f(r) / f(p)
  
  \[ f(r) = \text{fraction of EV}(r) \text{ unusable} \]
  
  \[ f(p) = \text{fraction of EV}(r) \text{ usable} \]
  
  \[ f(r) + f(p) = 1 \]

- Portion of EV(r) usable

  \[ f(p) \times R\% + f(p) = 1 \]

  \[ f(p) = \frac{1}{(1 + R\%)} \]
Effective Earned Value

- Effective earned value is a function of EV, P, and Rework: \( EV(e) = f (EV, P, \text{Rework}) \)
  
  \[
  EV(e) = EV(p) + (\text{fraction usable}) \times EV(r)
  \]
  
  \[
  = P \times EV + (1 / (1 + R\%)) \times [(1 - P) \times EV]
  \]

- General equation for Effective Earned Value
  
  \[
  EV(e) = \left[ \frac{(1 + P \times R\%)}{(1 + R\%)} \right] \times EV
  \]

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

- Effective ES is computed using $\text{EV}(e)\{i.e., \ E\!S(e)\}$

- Effective EV and ES indicators are ...
  - $\text{CV}(e) = \text{EV}(e) - \text{AC}$
  - $\text{CPI}(e) = \text{EV}(e) / \text{AC}$
  - $\text{SV}(te) = \text{ES}(e) - \text{AT}$
  - $\text{SPI}(te) = \text{ES}(e) / \text{AT}$
Graphs of CPI, CPI(e) & P - Factor (notional data)
Graphs of CPI & SPI(t) with the P - Factor

Percent Complete

Index Value

CPI
CPI(e)
SPI(t)
SPI(te)
P- Factor
Forecasting with Effective Earned Value
# Forecasting with Effective Earned Value

<table>
<thead>
<tr>
<th>Schedule Prediction</th>
<th>IEAC(te) = PD / SPI(te)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost Prediction</td>
<td>IEAC(e) = BAC / CPI(e)</td>
</tr>
</tbody>
</table>
Schedule & Cost Prediction

Cost Forecast Comparison

\[ \text{BAC} = \$1,000,000 \]

Schedule Forecast Comparison

\[ \text{PD} = 36 \text{ months} \]
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
Statistical Prediction
Statistical Prediction

- Statistical Process Control
- Planning for Risk
- Performance Indication & Analysis
- Outcome Prediction
Application Problems

- Distributions of periodic values of CPI & SPI(t) are right-skewed
  - Logarithms transform to Normal Distribution
- Research indicates CPI tends to worsen as 
  \[ \text{EV} \Rightarrow \text{BAC} \]
  - Statistics application assumes lack of any tendency
  - Effective EV used to remove tendency
Statistical Process Control

- SPC is a Quality method used to identify anomalous behavior of the process
- For application to CPI and SPI(t), SPC is used to identify anomalous periodic performance
  - Clarifies “true” performance
  - Allows better analysis
  - Improves prediction
Statistical Process Control

![Chart showing statistical process control with an anomaly highlighted.](chart.png)

- $\langle \ln \text{SPI}_t \rangle_u = 0.994$
- $\sigma = 0.266$

Anomalies are marked with a red circle.
Planning for Risk

- Risk mitigation ⇒ Schedule Reserve
- Data needed
  - Performance variation from similar historical project
    
    \[ \text{Standard Deviation} = \sigma_H \]
  
  - Planned Duration of new project [provides the number of performance observations (n)]
  - Variation of Means (\(\ln \text{SPI}(t)_{m-1}\)) = \(\sigma_H / \sqrt{n} = \sigma_m\)
  - Probability of Success Desired (PS)
Planning for Risk

In SPI(t)⁻¹

Area of Success

In Schedule Ratio

Failure

Relative Frequency

Means (ln SPI(t)m⁻¹)
Performance Indication & Analysis

- **Performance Window Indicator**
  - Combines CPI & SPI(t) onto one chart
  - Depiction is invariant to project size
  - Provides visual of performance in relation to Plan & Negotiated requirement
  - Illustrates diminishing opportunity for recovery
  - Provides *Probability of Success* separately for Cost & Schedule
Performance Indication & Analysis

Note: Graph axes scales are multipliers of Budget at Completion (Cost) and Period of Performance (Time).

Plan
$PS_c = PS_s = 0.565$

~ 50% Complete
$PS_c = PS_s = 0.772$

Red - Failure
Green - Plan
Yellow - Reserves

Cost distribution

Cost

Time

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Lipke and Henderson

ProMAC 2006 26th Sep 2006
Outcome Prediction

- Apply SPC to establish “true” performance for CPI & SPI(t)
  - Residual Cumulative value
  - Standard Deviation of periodic performance
- Compute the adjustment for accomplished portion of project
- Compute adjusted Standard Deviation of the Means ($\sigma_*$)
Outcome Prediction

- Using the results...
  - Determine *Confidence Limits* for the Performance Window – e.g., 95% confidence 
    ....that is, the high and low expectations for performance
  - Calculate *Probability of Success* for both Cost & Schedule separately
Summary - Advanced
Summary - Advanced

- Project analysis tool [EV & ES application]
- Re-baseline impacts SPI(t) similarly to CPI
- Duration prediction from ES much easier than using Critical Path analysis ...and may be better
- Network schedule analysis enhanced by ES
  - Identifies future problems
Summary - Advanced

- ES connects EV to the schedule
  - Schedule Adherence
  - Effective Earned Value
  - Possible enhancement of outcome prediction for schedule & cost

- Statistical techniques provide facility to improve planning, analysis, and outcome prediction
Quiz & Discussion
Question #1

- What is the problem with the EVM schedule indicators, SV and SPI?
  - They measure schedule performance in $$
  - They sometimes are erroneous
  - They can be poor predictors of outcome
  - All of the above
Question #2

- Why do SPI & SV fail to provide reliable schedule information?

- EVM measures schedule performance in $$
- PV & EV are constrained to BAC
- They are not related to the networked schedule
- All of the above
Question #3

- What elements are required to compute Earned Schedule?

- AT & EV
- AC & PMB
- EV & PV
- EV & PMB
- All of the above
Question #4

- What does Earned Schedule measure?
  - Time at which Actual Cost appears on PMB
  - Time at which Planned Value equals Earned Value
  - Time at which Earned Value is reported
  - None of the above
Question #5

- The equation for Earned Schedule is $ES_{cum} = C + I$. How is $I$ calculated?

- $I$ must be determined graphically
- $I = EV / PV$
- $I = (EV - PV_C) / (PV_{C+1} - PV_C)$
- $I = \Delta EV / \Delta PV$
Question #6

- What is the largest source of error for the Earned Schedule measure?

- Earned Value reported
  - Interpolated portion of the ES value
  - Earned Value accounting practice
  - Crediting first month as a full month
Question #7

- Earned Schedule can be used to provide information about future rework and project constraints and impediments.

- True
- False
Question #8

What fundamental elements are needed to predict the completion date for a project?

- Date + AC, EV, PV
- Date + AC, AT, PMB
- Date + PMB, EV, AT
- Date + PV, PMB, AT
- Date + ES, AT, PD
Question #9

- What does the P-Factor help us understand about project performance?
  - How closely the project is following its plan
  - Why performance has the tendency to become less efficient as \( EV \Rightarrow BAC \)
  - Improves analysis of true project accomplishment
  - All of the above
Question #10

How does Effective Earned Value differ from Earned Value?

- Effective EV ≤ EV
- Effective EV accounts for rework
- Allows for earlier prediction of final project outcome
- All of the above
- None of the above
Wrap-Up
Wrap Up

- Derived from EVM data ... only
- Provides time-based schedule indicators
- Indicators do not fail for late finish projects
- Application is scalable up/down, just as is EVM
- Schedule prediction is better than any other EVM method presently used
  - SPI(t) behaves similarly to CPI
  - IEAC(t) = PD / SPI(t) behaves similarly to IEAC = BAC / CPI
Wrap Up

- Schedule prediction – much easier and possibly better than “bottoms-up” schedule analysis
- Facilitates bridging EVM to schedule analysis
  - Identification of Constraints / Impediments and Rework
  - Calculation of Schedule Adherence
  - Creation of Effective Earned Value

Leads to improved Schedule & Cost Forecasting
Conclusion

- “Whatever can be done using EVM for Cost Analysis can also be done using Earned Schedule for Schedule Analysis”

- Earned Schedule
  - A powerful new dimension to Integrated Project Performance Management (IPPM)
  - A breakthrough in theory and application
# Contact Information

<table>
<thead>
<tr>
<th>Walt Lipke</th>
<th>Kym Henderson</th>
</tr>
</thead>
<tbody>
<tr>
<td><a href="mailto:waltlipke@cox.net">waltlipke@cox.net</a></td>
<td><a href="mailto:kym.henderson@froggy.com.au">kym.henderson@froggy.com.au</a></td>
</tr>
<tr>
<td>(405) 364-1594</td>
<td>61 414 428 537</td>
</tr>
</tbody>
</table>