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Earned Schedule

…an extension to EVM theory

Sweden EVM Conference
Stockholm, Sweden
February 9, 2005

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Purpose

To discuss and encourage the application of a new method of schedule analysis derived from EVM, termed *"Earned Schedule."*

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Overview

- Introduction to *Earned Schedule*
- Terminology & Status
- Application Results
- Extension to Prediction
- Network Schedule Analysis
- Concept of *Effective Earned Value*
- Summary

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Background

- SEI SW-CMM Level 4 achieved Nov 1996
- Level 4 evolved ⇔ SPC
- SPC ⇔ Defect Prevention (Level 5)
- SPC applied to EV indicators
- Several applications of statistics created
- SPI flaw became intolerable
- Solution needed to save statistics applications

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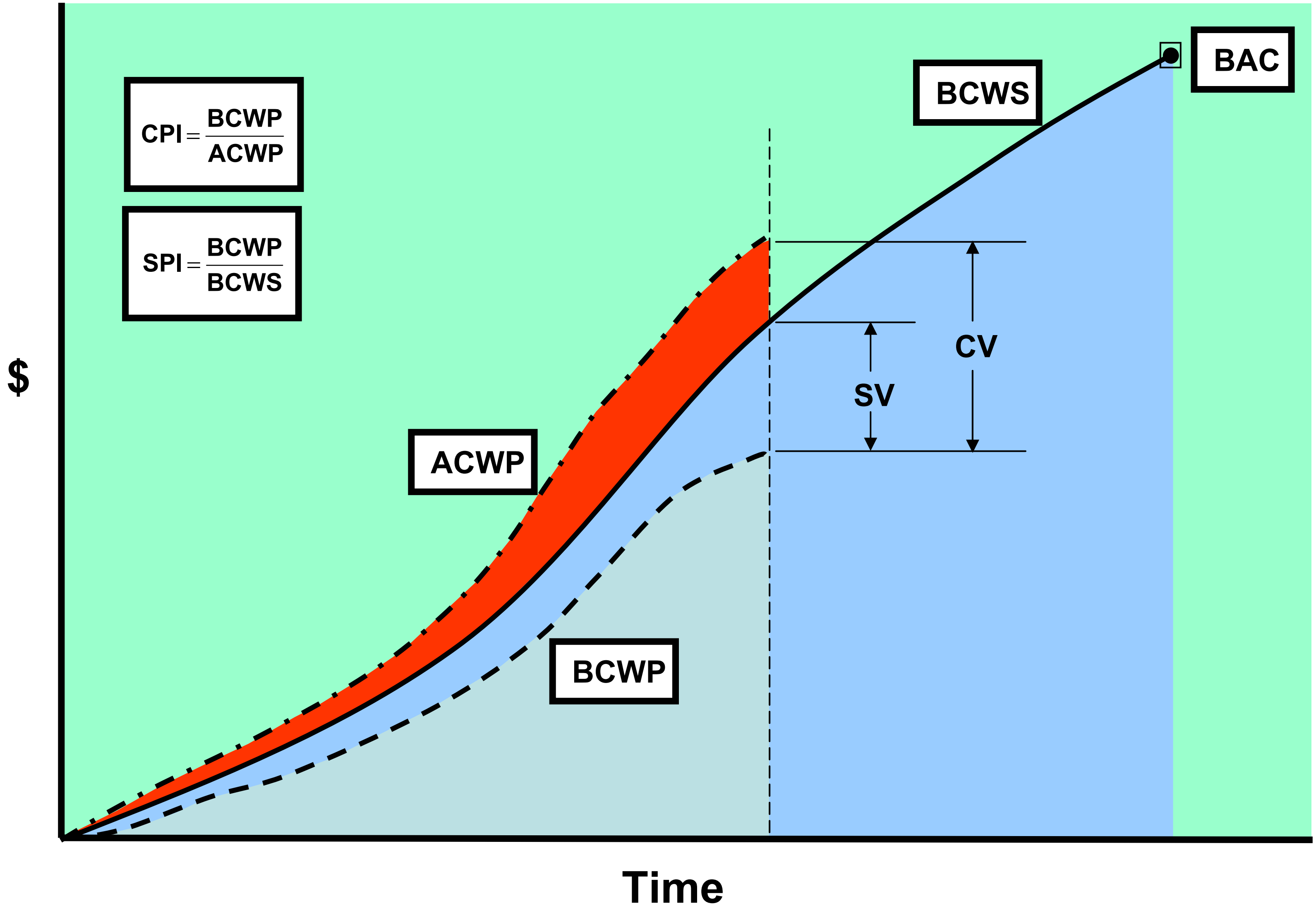
Earned Value Basics



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!

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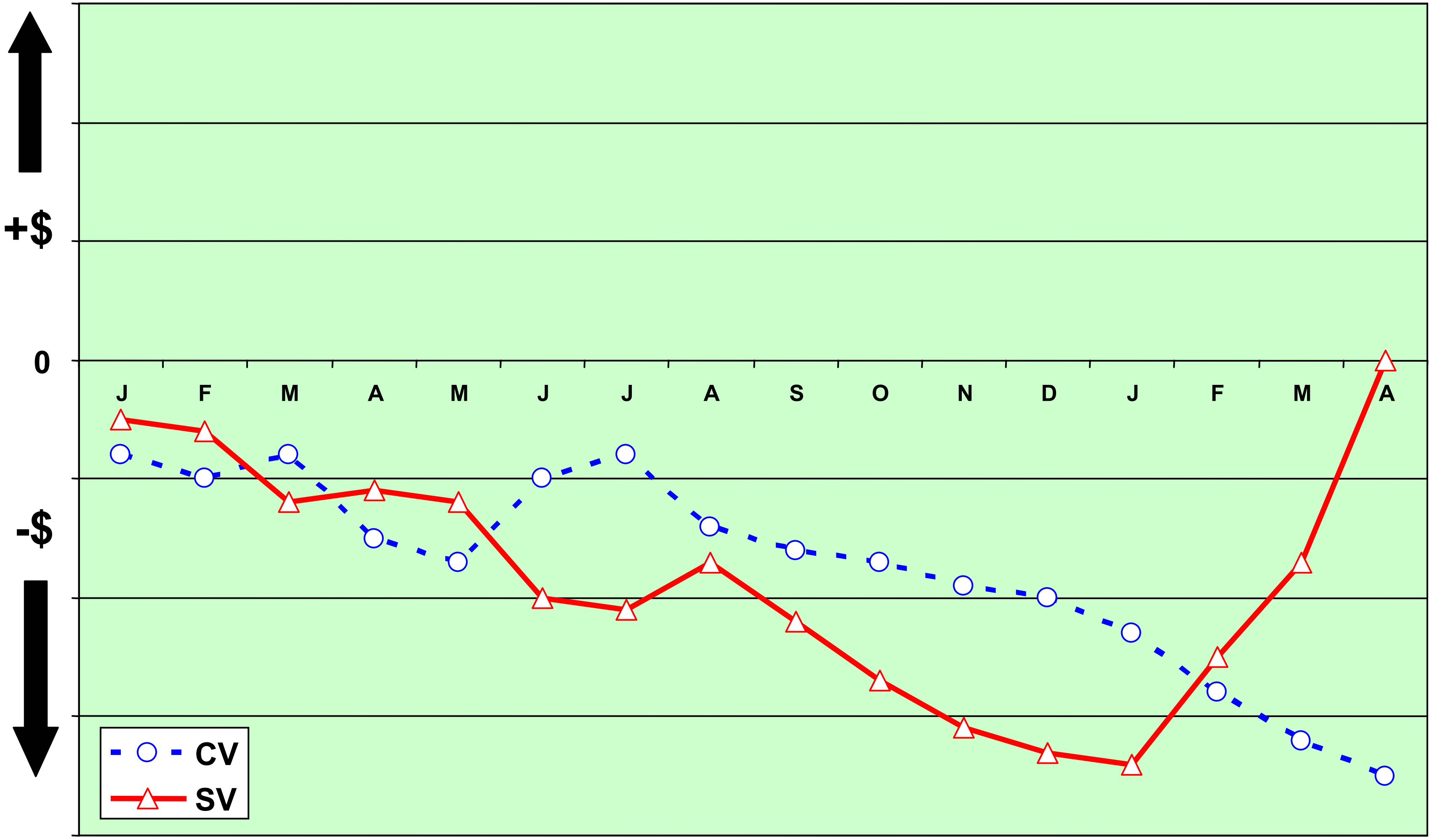
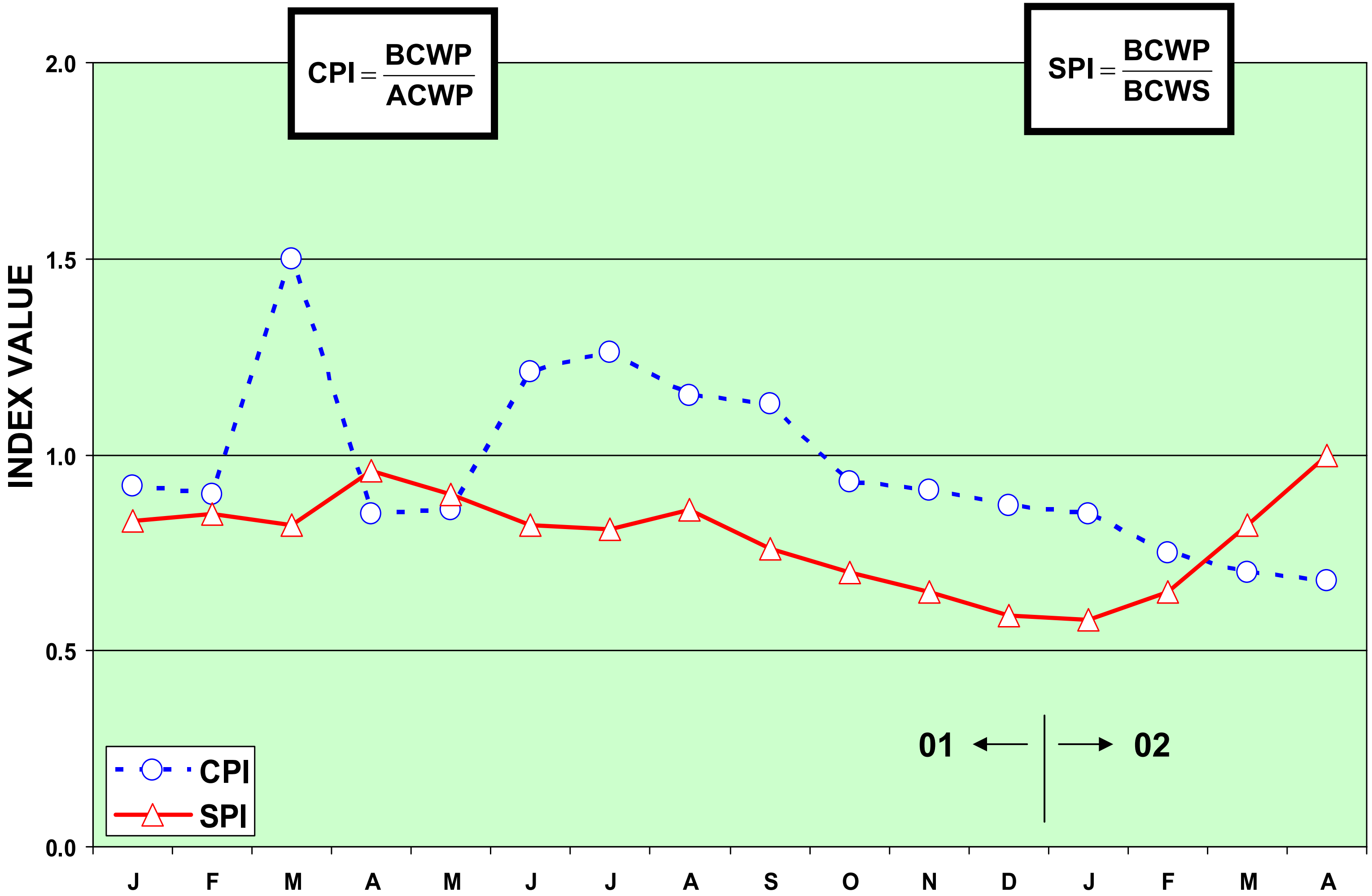
Earned Value
Cost and Schedule Variances



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

Earned Value Cost and Schedule Performance Indices



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

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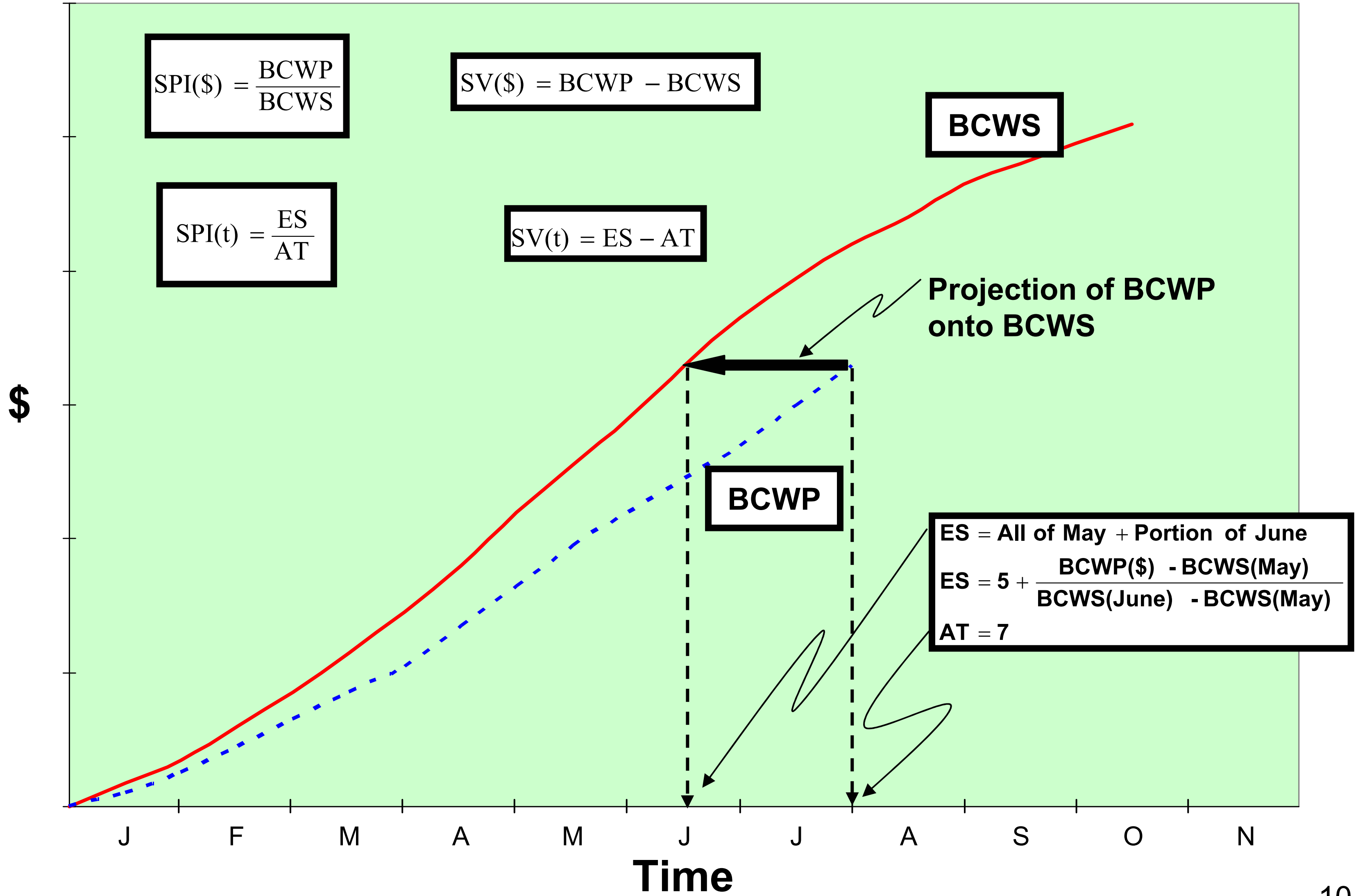
Earned Schedule Concept

Earned Schedule Concept



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Earned Schedule: The Formulae

- **EScum is the:**

  Number of completed BCWS time increments BCWP exceeds + the fraction of the incomplete BCWS increment

- **ES_{cum} = C + I where:**

  C = number of time increments for BCWP $\geq$ BCWS

  $I = (BCWP - BCWS_C) / (BCWS_{C+1} - BCWS_C)$

- **ESperiod(n) = EScum(n) – EScum(n-1)**

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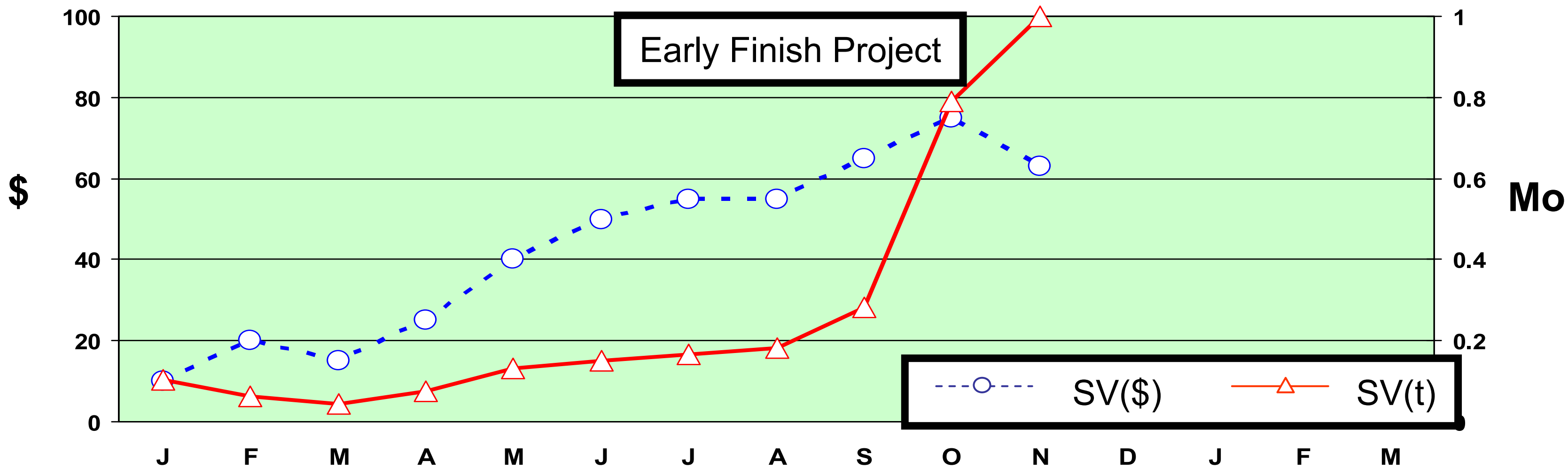
Earned Schedule: The Schedule Indicators

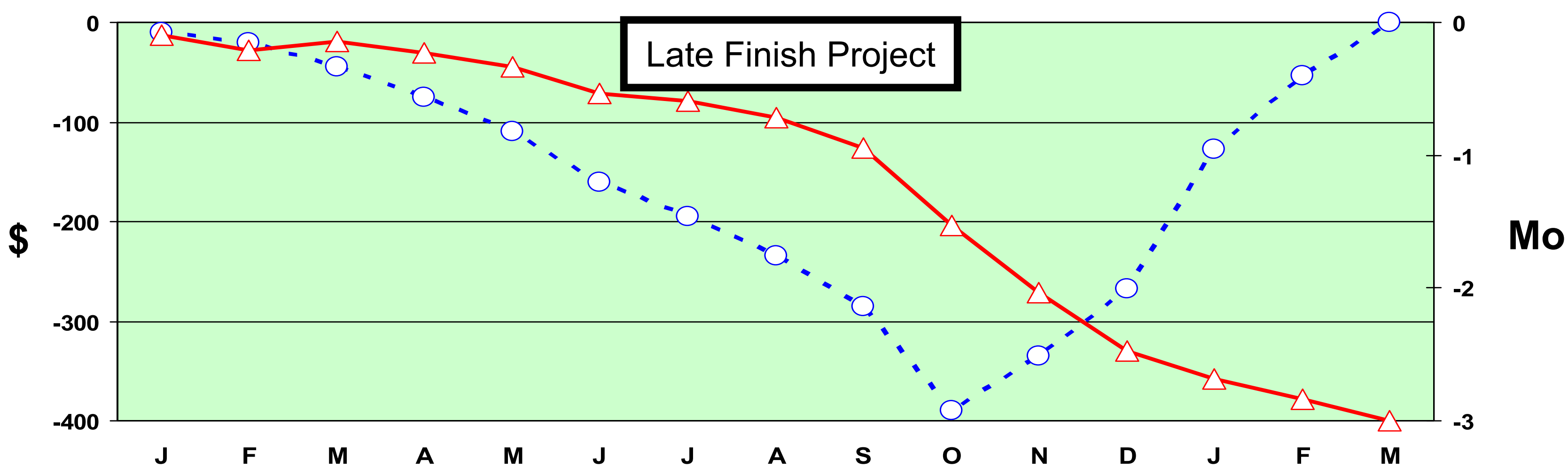
- **The Earned Schedule Indicators**
  - Schedule Variance (time):

    SV(t) = ES – AT, where AT = actual time
  - Schedule Performance Index (time):

    SPI(t) = ES / AT
- **Key Points:**
  - ES Indicators constructed to behave in an analogous manner to the EVM Cost Indicators, CV and CPI
  - SV(t) and SPI(t) <u>not</u> constrained by BCWS calculation reference
  - SV(t) and SPI(t) provide <u>duration</u> based measures of schedule performance

Schedule Variance Comparison





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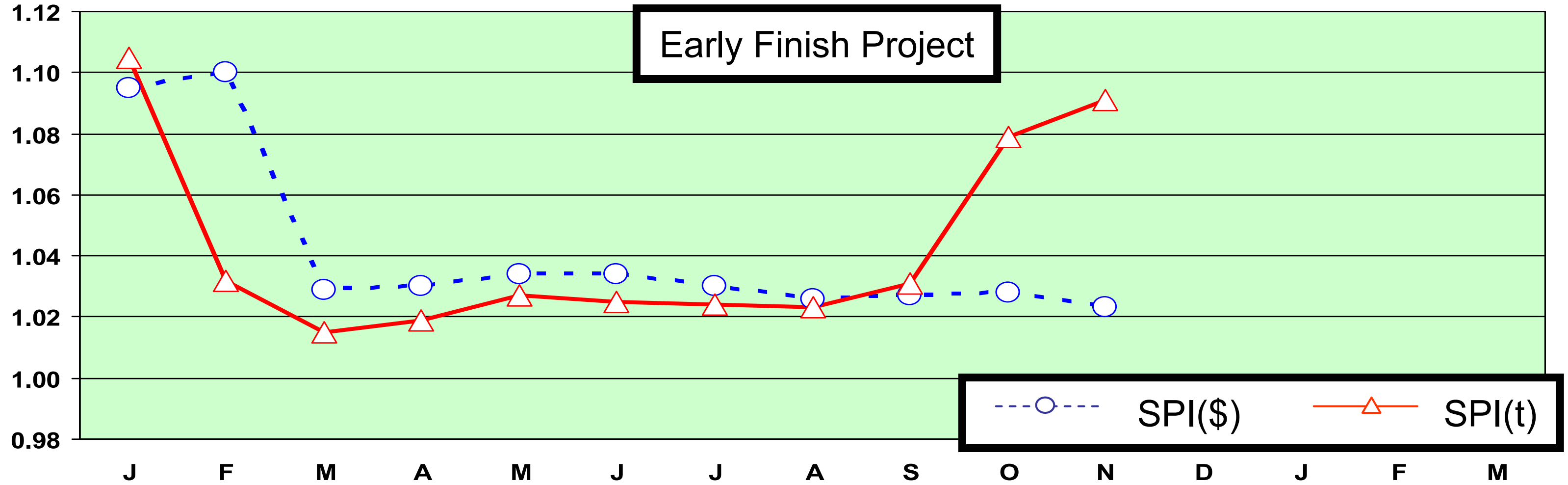
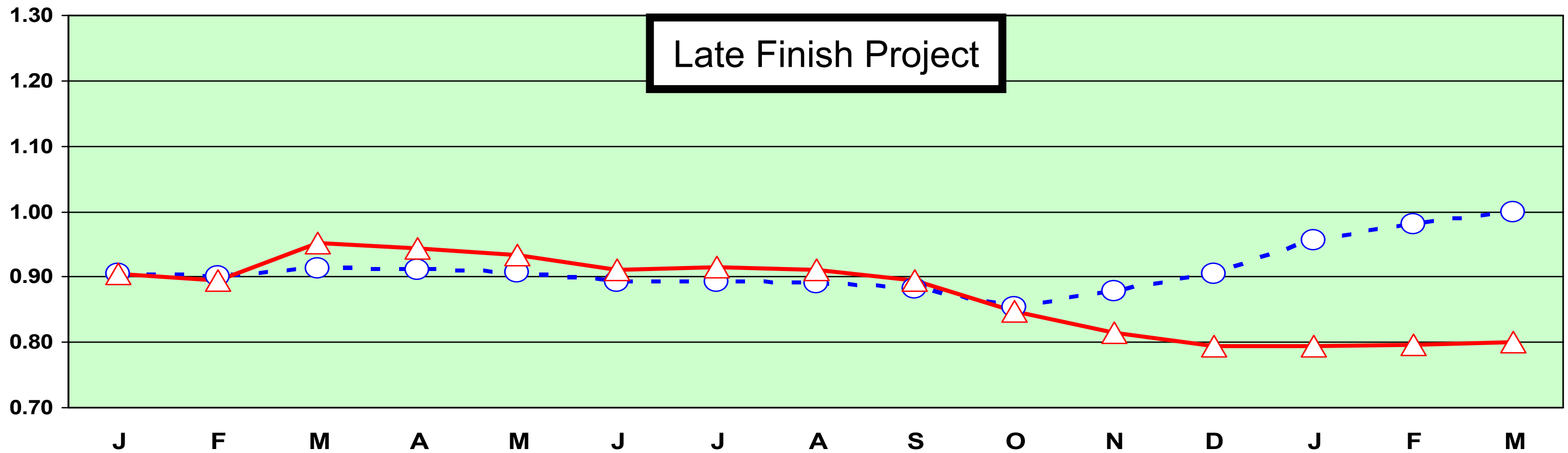
Schedule Performance Index Comparison





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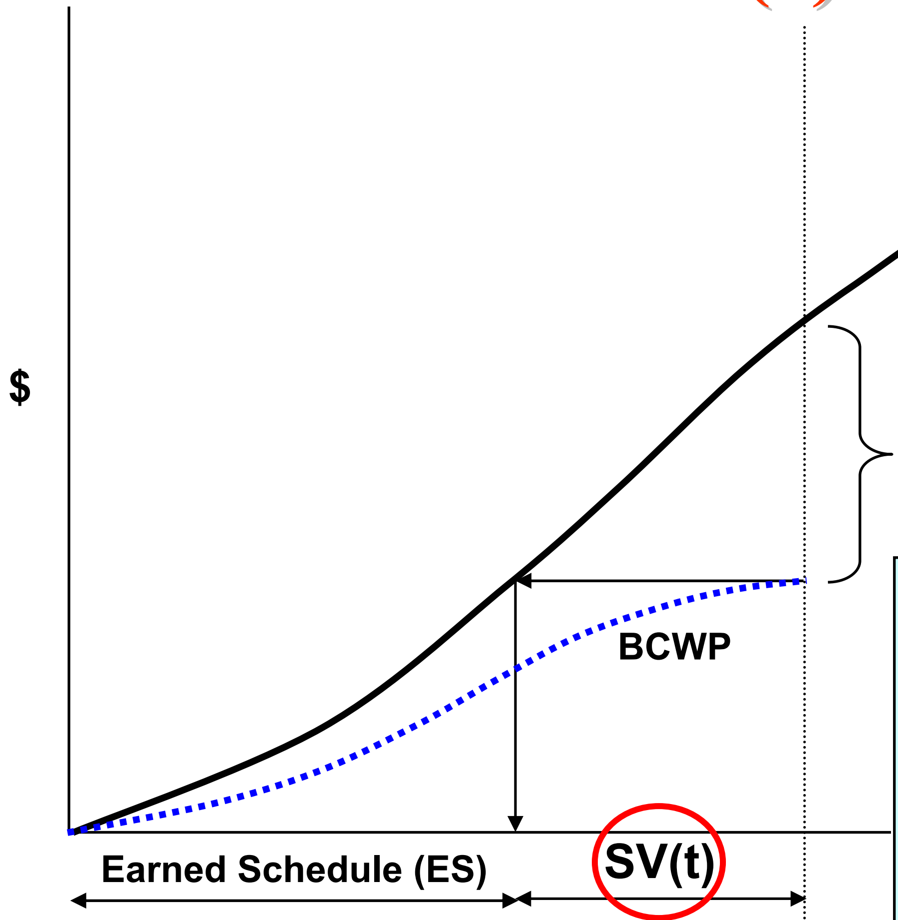
ES vs EVM Schedule Indicators

Earned Schedule	Earned Value
SV(t) and SPI(t) valid for entire project, including early and late finish	SV($) and SPI($) validity limited to early finish projects
Duration based predictive capability analogous to EVM's cost based indicators	Limited prediction capability No predictive capability after planned completion date exceeded
Facilitates Cost – Schedule Management (using EVM and ES)	EVM Management focused to Cost

SV($) versus SV(t)



- **Earned schedule metrics relate work performed to actual time, not work scheduled**
- **Retain utility over time**
  - **Only return to 0 or 1.00 where "on time" completion achieved**

Actual Time

Terminology & Status

Earned Schedule Terminology Parallels EVM

	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)

Review of Earned Schedule continued

- **Inclusion of Emerging Practice Insert into EVM Practice Standard**
  - Dr. John Singley
- **Launch of PMI-CPM Research**
  - Valid for large scale DOD projects?
  - AFIT Master's student: 1Lt Scott Smith
  - Research oversight: Dr. David Christensen
- **Evidence of "early adopters" including in EVM practice**
  - Incorporation of ES into EVM Instruction
  - Requests for information and ES calculator

"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 released at 2004 IPMC Conference

Box 3-1: Time-Based Schedule Measures -- An Emerging EVM Practice

In the current practice of EVM, schedule variance and schedule performance are both measures of work scope, not time. The work is represented by its budgeted cost as recorded in the performance measurement baseline. The EVM schedule variance is the difference between work performed and work scheduled, and the schedule performance index is the ratio of work performed to work scheduled. For Project EZ, these measures indicate that work is not being accomplished as quickly or as efficiently as planned:

$SV = EV - PV = 32 - 48 = -16$ $SPI = EV / PV = 32 / 48 = 0.67$

If the work were to continue at this rate, then all of the work of Project EZ would take 18 months to accomplish instead of the 12 months planned (12 / 0.6667 = 18).

These SV and SPI measures are useful indicators and predictors of performance and results. But, because they are based on work and not time, they can behave in ways that are not normally expected of schedule indicators and predictors. The problem can be illustrated with Project EZ: Whether all of the work is completed as planned at 12 months or at 18 months as predicted by the four-month SPI of 0.67, it will be completed eventually and at that time the work-based schedule variance and performance index will indicate perfect performance. For when the work is completed: EV = PV, and so SV = 0 and SPI = 1.0. This is fine if the work is being accomplished according to plan, but problematic if it is not. If Project EZ does take 18 months, SV will nonetheless equal 0 and SPI equal 1.0, when it's clear that Project EZ is 6 months late and averaged only 67% efficiency.

There is an emerging practice in EVM, which uses time-based measures of schedule variance and schedule performance as an alternative or supplement to the traditional work-based measures. This new method avoids the problems of the work-based method illustrated above. Whereas the traditional work-based method compares work performed and work scheduled at or to a point in time, the time-based method compares the *actual time* with the *planned time* for the work performed. In the case of Project EZ, the work performed after four months (AT = 4) had a planned time of three months (PT = 3) [refer to Figures 2-6 and 2-7]. In a manner that parallels the use of AC and EV in traditional EVM, practitioners are beginning to use actual time (AT) and planned time (PT) to compute SV and SPI:

$SV(t) = PT - AT = 3 - 4 = -1$ month $SPI(t) = PT / AT = 3 / 4 = 0.75$

While the work- and time-based methods provide comparable results at the four-month point in Project EZ, look at the difference at project completion after 18 months:

$SV(t) = PT - AT = 12 - 18 = -6$ months $SPI(t) = PT / AT = 12 / 18 = 0.67$

$SV(\$) = EV - PV = 160 - 160 = 0$ $SPI(\$) = EV / PV = 160 / 160 = 1.0$

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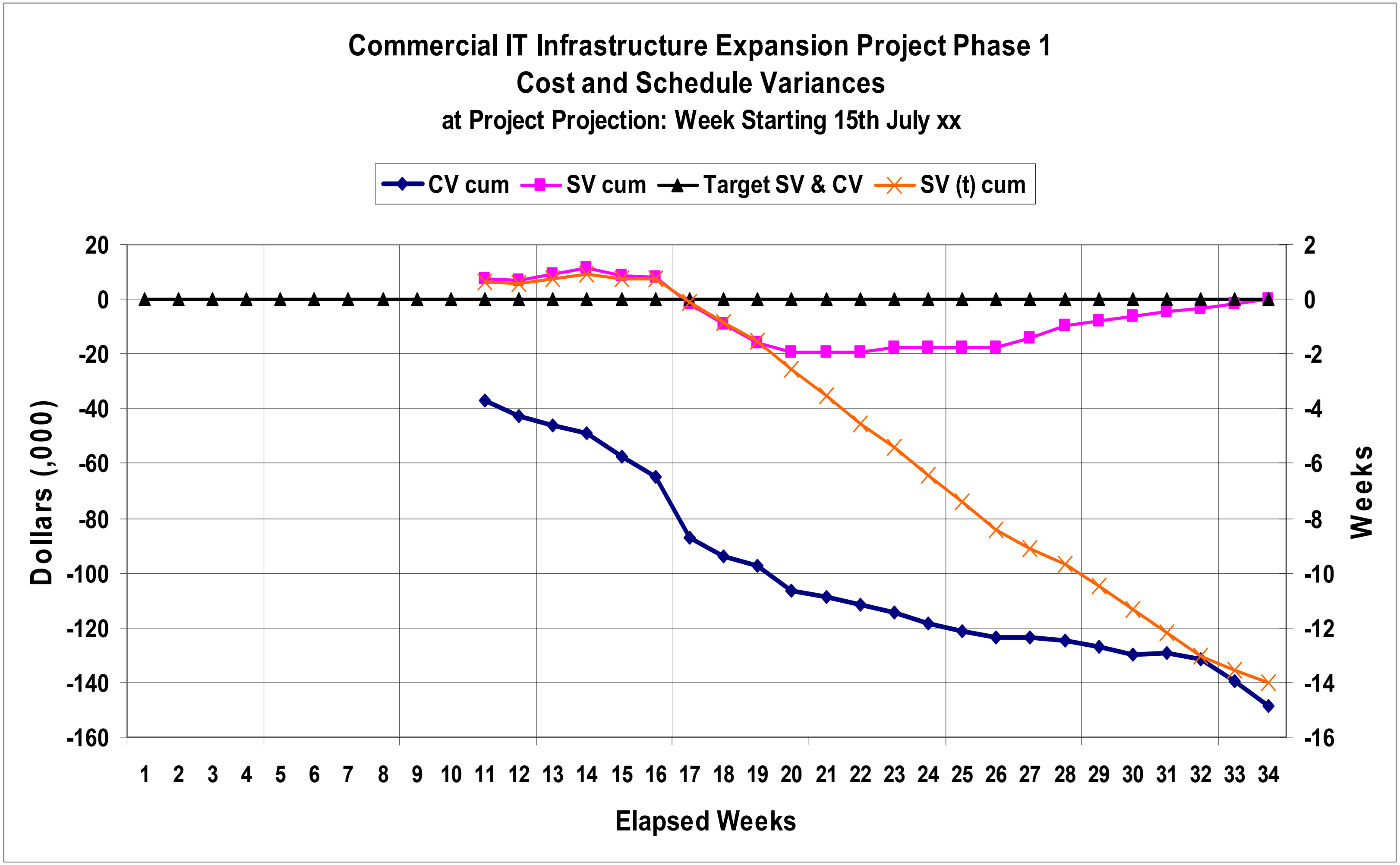
Application Results

ES Applied to Real Project Data:
Late Finish Project: SV($) and SV(t)

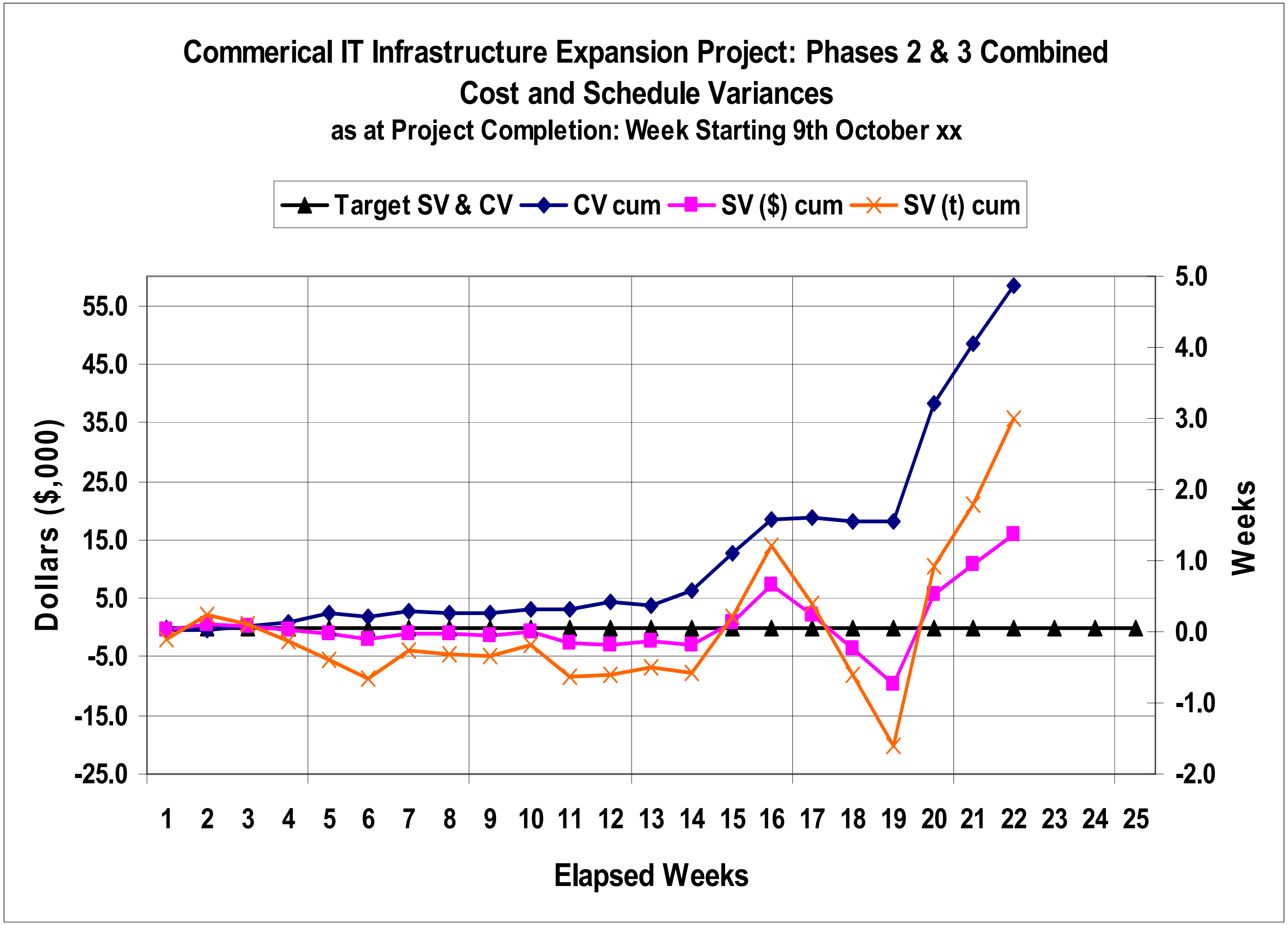


ES Applied to Real Project Data:

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 analysing schedule performance**

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



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 analysing schedule performance**

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Duration Prediction

"Further Developments" in Earned Schedule

Schedule Duration Prediction Techniques

- Calculation of IEAC(t): short form

IEAC(t) = Planned Duration / SPI(t)

- Planned Duration for Work Remaining

PDWR = Planned Duration – Earned Schedule cum

  – Analogous to the EVM BCWR

- Calculation of IEAC(t): long form

$$IEAC(t) = Actual\ Time + \left(\frac{PDWR}{Performance\ Factor}\right)$$

"Further Developments" in Earned Schedule

Schedule Duration Prediction Techniques *(continued)*

- IEAC(t) long form formula
  - Provides full alignment to the EVM IEAC($) predictor
  - Allows performance factors other than SPI(t) to be developed and utilised for predicting final schedule outcomes
    - Including non EVM based formulae (i.e. schedule based PF)
  - PDWR resolves to zero at project completion
- IEAC(t) formulae overcome flaws in pre-Earned Schedule, schedule predictive techniques using EVM
  - e.g. **Planned Duration / SPI($)**

Pre ES, Schedule Prediction Techniques

- Pre ES, schedule prediction techniques using EVM indicators have been developed and published:
  - Described in "*Earned Value Project Management Method and Extensions*" Prof. Frank T Anbari, Phd, George Washington University) [Published PMI Journal, Dec 2003]
  - EVM: Earned Value Management Handbook, Japanese Society for Project Management, 2003
- These pre ES IEAC(t) formulae use **SPI($)** or a combination of factors including SPI($) as performance factors. e.g.
  - **Planned Duration / SPI($)** or **Critical Ratio (CR)**
    - **CR defined as product of CPI ∗ SPI($) [Anbari]**

IEAC(t) Predictions using pre ES Techniques:

Early and Late Finish Project Examples

IEAC(t) Metrics at Project Completion Early Finish Project	
Planned Duration (weeks)	25
Actual Time (weeks)	22
Percentage Complete cum	100%
CPI cum	2.08
SPI(t) cum	1.14
SPI($) cum	1.17
Critical Ratio cum	2.43
IEAC(t) PD/SPI(t) cum	22.0
IEAC(t) PD/SPI($) cum	21.4
IEAC(t) PD/CR cum	10.3

IEAC(t) Metrics at Project Completion Late Finish Project - pre ES	
Planned Duration (weeks)	20
Actual Time (weeks)	34
Percentage Complete cum	100%
CPI cum	0.52
SPI(t) cum	0.59
SPI($) cum	1.00
Critical Ratio cum	0.52
IEAC(t) PF = SPI(t) cum	34.0
IEAC(t) PF = SPI($) cum	20.0
IEAC(t) PF = CR cum	38.7

- 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 Techniques *(continued)*

- **<u>Pre ES formulae and results algebraically flawed</u>**

  “... 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.”

- Reference: *“Further Developments in Earned Schedule”* (Henderson) provides detailed explanation

IEAC(t) Predictions using ES Techniques:

Same Early and Late Finish Project Examples

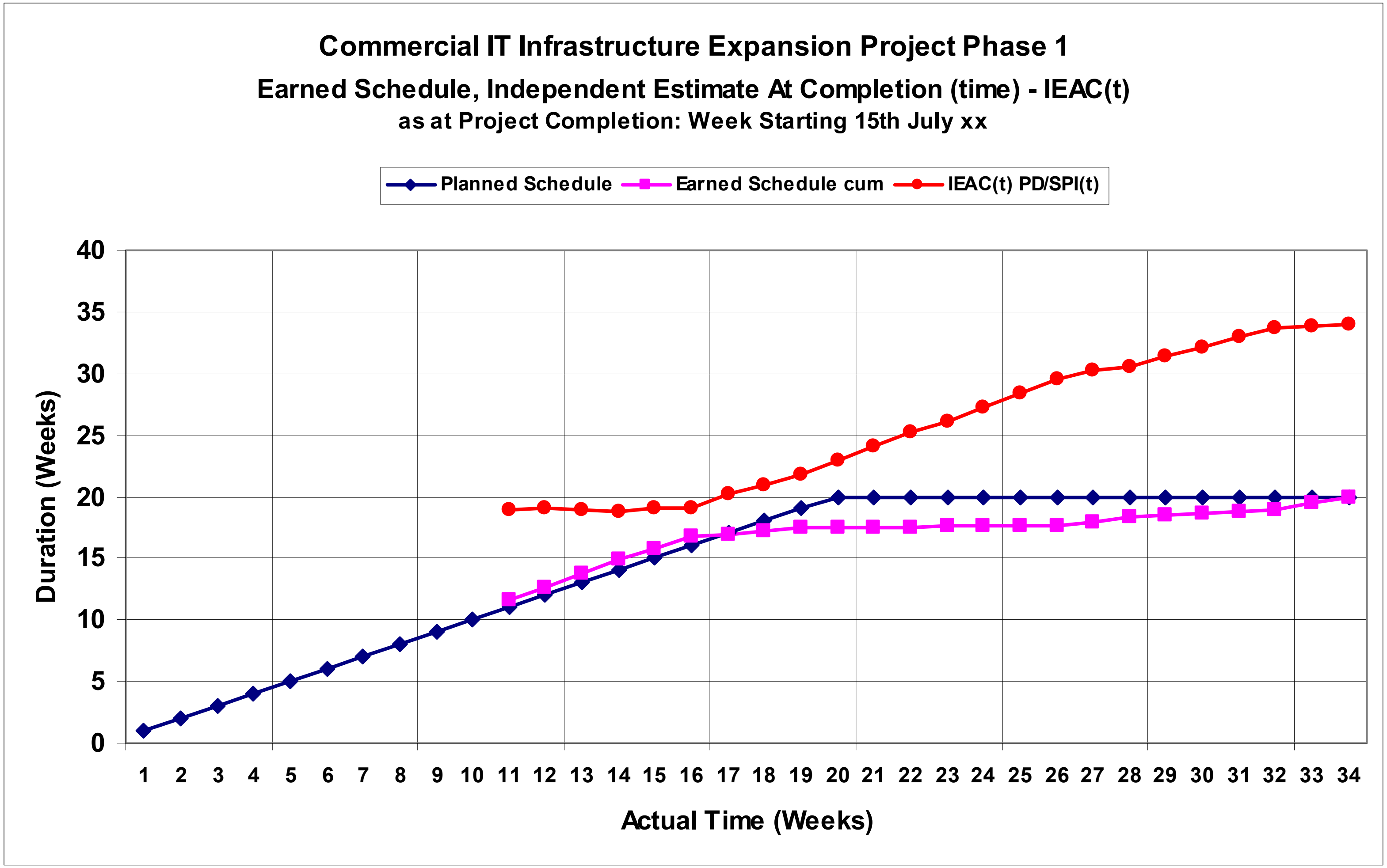
IEAC(t) Metrics at Project Completion Early Finish Project using ES	
Planned Duration (weeks)	25
Actual Time (weeks)	22
Earned Schedule cum	25.0
Planned Duration Work Remaining	0.0
Percentage Complete cum	100%
CPI cum	2.08
SPI(t) cum	1.14
SPI($) cum	1.17
Critical Ratio cum	2.43
Critical Ratio ES cum	2.37
IEAC(t) PF = SPI(t) cum	22.0
IEAC(t) PF = SPI($) cum	22.0
IEAC(t) PF = CR cum	22.0
IEAC(t) PF = CR ES cum	22.0

IEAC(t) Metrics at Project Completion Late Finish Project using ES	
Planned Duration (weeks)	20
Actual Time (weeks)	34
Earned Schedule cum	20.0
Planned Duration Work Remaining	0.0
Percentage Complete cum	100%
CPI cum	0.53
SPI(t) cum	0.59
SPI($) cum	1.00
Critical Ratio cum	0.52
Critical Ratio ES cum	0.30
IEAC(t) PF = SPI(t) cum	34.0
IEAC(t) PF = SPI($) cum	34.0
IEAC(t) PF = CR cum	34.0
IEAC(t) PF = CR ES cum	34.0

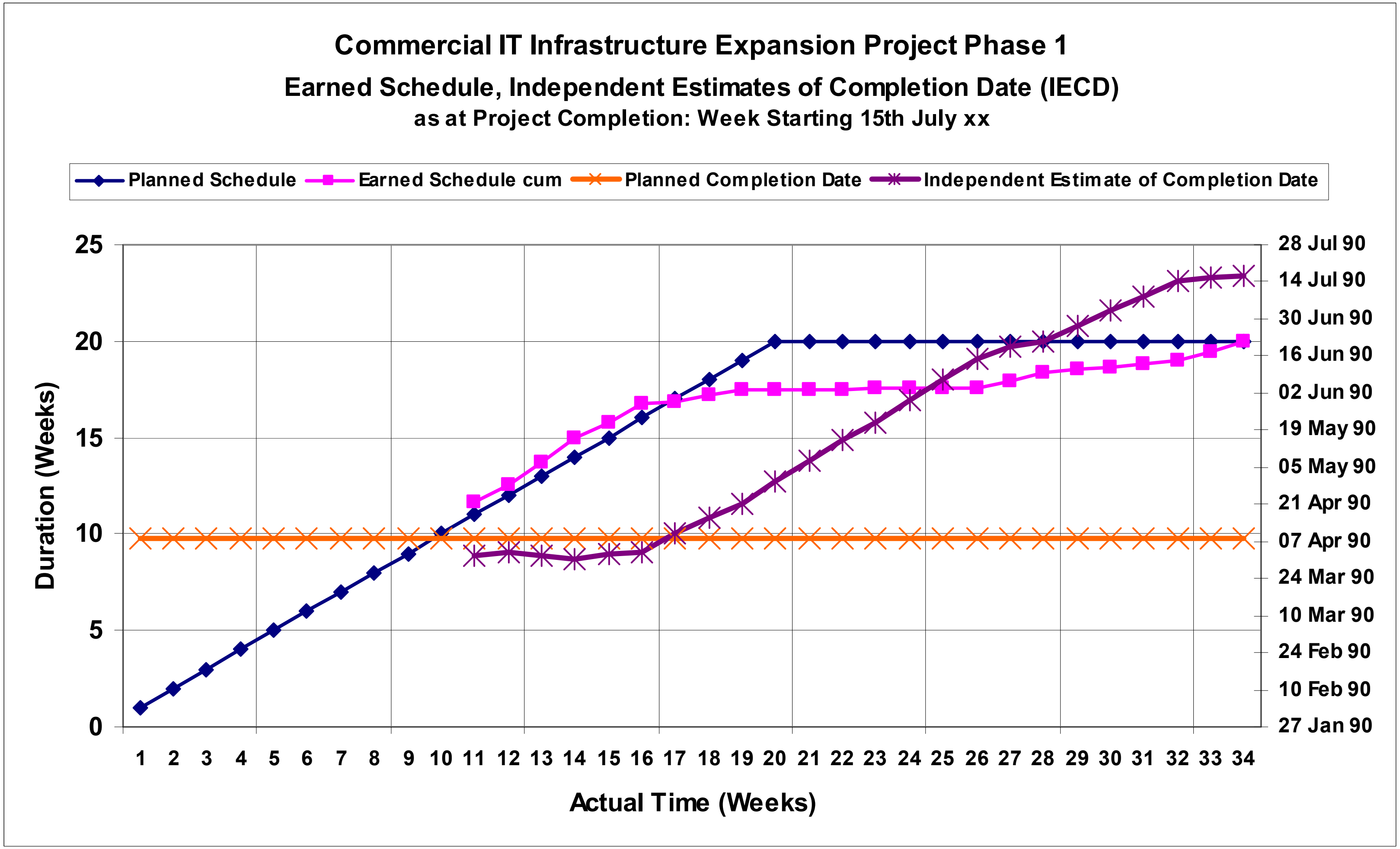
- Use of the ES "long form" IEAC(t) formula, results in **correct** calculation of Actual Duration at Completion

IEAC(t) Predictions using ES Techniques: *(continued)*

Weekly Plots of IEAC(t) - Late Finish Project Example



IECD Predictions using ES Techniques:
Weekly Plots of Independent Estimate of Completion Date



IEAC(t) Predictions using <u>ES</u> Techniques:

- **<u>ES formulae and results are algebraically correct</u>**

  "Whilst assessments of the predictive utility of the ES calculated IEAC(t) and the relative merits of using the various performance factors available are matters for further research and empiric validation, the theoretical integrity of ES now seems confirmed."

- Reference: *"Further Developments in Earned Schedule"* (Henderson) provides detailed explanation

"Further Developments" in Earned Schedule

(continued)

- Analogous forward looking" Earned Schedule indicator to the CPI TO GO is calculated as:

$$\text{SPI(t)}_{\text{TO GO}} = \frac{\text{Planned Duration} - \text{ES}_{\text{cum}}}{\text{Planned Duration} - \text{Actual Time}}$$

- The ES analogous To COMPLETE CPI indicator is calculated as:

$$\text{To COMPLETE SPI(t)} = \frac{\text{Planned Duration} - \text{ES}_{\text{cum}}}{\text{EAC(t)} - \text{Actual Time}}$$

- **Achieves full ES parity with EVM indicators for cost**

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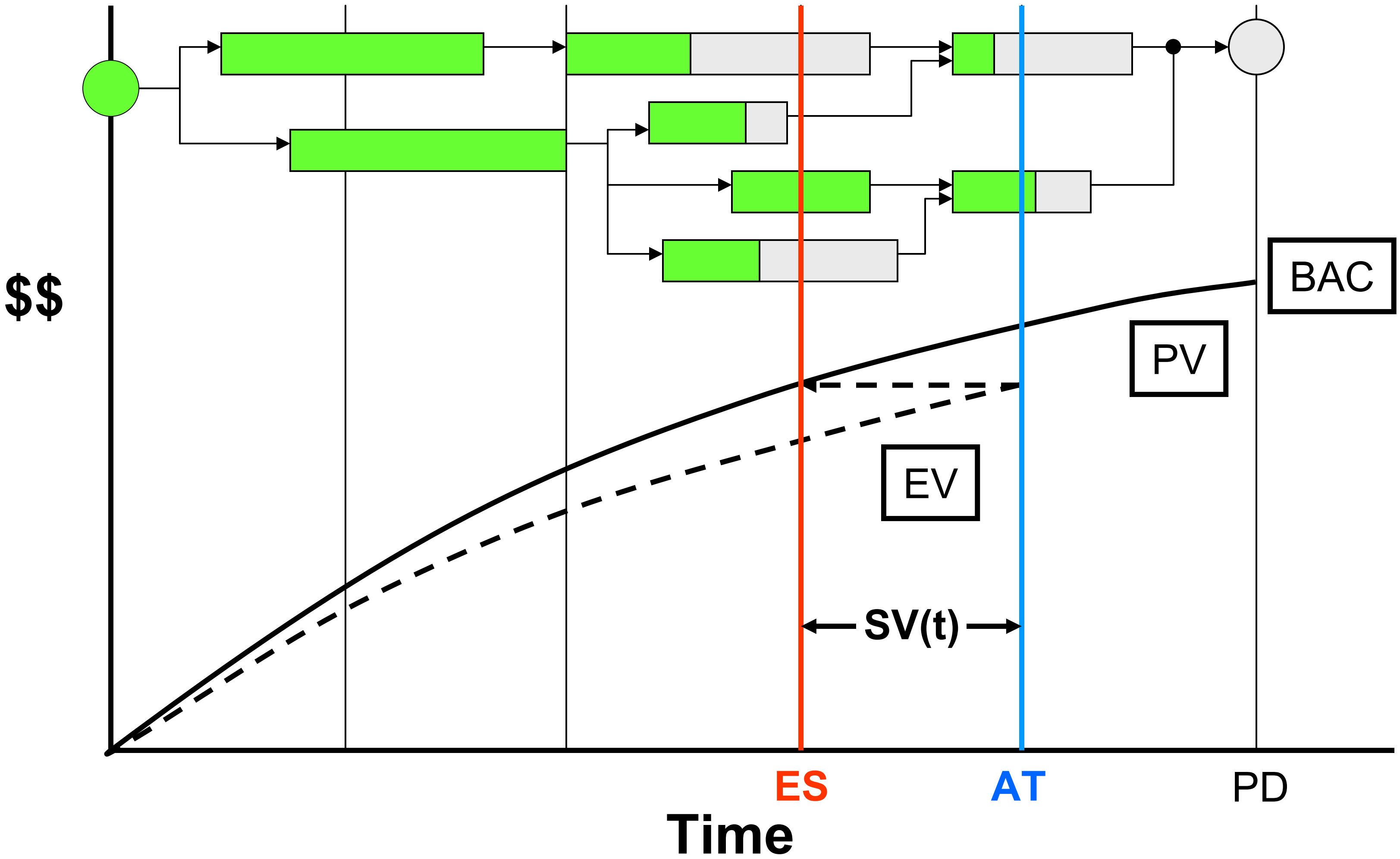
Schedule Analysis

Earned Schedule

Bridges EVM to "Real" Schedule



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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!!**

Concept:
Effective Earned Value

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CPI & SPI(t) Behavior

CPI & SPI(t) tend to decrease as EV ⇒ BAC -- Why?

- **EV isn't connected to task sequence**

Hypothesis: Completion sequence of tasks affects performance efficiency

Assertion: If tasks are not interdependent, nor are there process constraints, then tasks can be performed in any sequence, using any resource loading; i.e., the critical path doesn't exist. For these conditions SPI(t) indicates schedule performance without reservation.

- **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**

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CPI & SPI(t) Behavior

CPI & SPI(t) tend to decrease as EV ⇒ BAC -- Why?

- **Result from improper performance sequence …**
  - **Constraint limited output**
    - **Schedule lengthens**
    - **Cost increased 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**

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CPI & SPI(t) Behavior

CPI & SPI(t) tend to decrease as EV ⇒ BAC -- Why?

- **IEAC(t) = PD / SPI(t) is likely an inconsistent predictor**
  - **Task sequencing has impact**
  - **Hypothesis: When task sequencing is maintained IEAC(t) provides a reasonable estimate for final duration.**

- **Schedule adherence needs to be an added EVM measure**
  - **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:

$$P = \text{Tasks (corr-actual)} / \text{Tasks (plan)} = \Sigma EV_j \text{ (corr-actual)} / \Sigma PV_j \text{ (plan)}$$

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CPI & SPI(t) Behavior

CPI & SPI(t) tend to decrease as EV ⇒ BAC -- Why?

- **Hypothesis: Use of the P measure with ES method will enhance schedule *(and cost)* prediction**
  - **P measure cannot exceed 1.0 [0 ≤ P ≤ 1.0]**
  - **At project completion P = 1.0**
  - **P used to compute earned value [EV(e)] ⇔ schedule progress**
  - **Effective ES is computed using EV(e) [ES(e)]**
  - **Effective schedule indicators are …**

Schedule Performance Index ⇒ SPI(te) = ES(e) / AT
Schedule Variance ⇒ SV(te) = ES(e) - AT

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CPI & SPI(t) Behavior

CPI & SPI(t) tend to decrease as EV $\Rightarrow$ BAC -- Why?

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

EV(e) = f (EV, P, Rework)

- **Cumulative EV = ΣEV_i (tasks) @ AT = ΣPV_j @ ES**
- **EV according to plan: EV(p) = P ∗ EV**
- **EV not according to plan: EV(r) = EV – EV(p) = (1 – P) ∗ EV**
- **Assuming EV(r) has 50% rework: 2/3 usable, 1/3 unusable**
- **Effective EV: EV(e) = EV(p) + 2/3 ∗ EV(r)**
  = P ∗ EV + 2/3 ∗ [(1 – P) ∗ EV]

EV(e) = [(P + 2) / 3] ∗ EV

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CPI & SPI(t) Behavior

CPI & SPI(t) tend to decrease as EV ⇒ BAC -- Why?

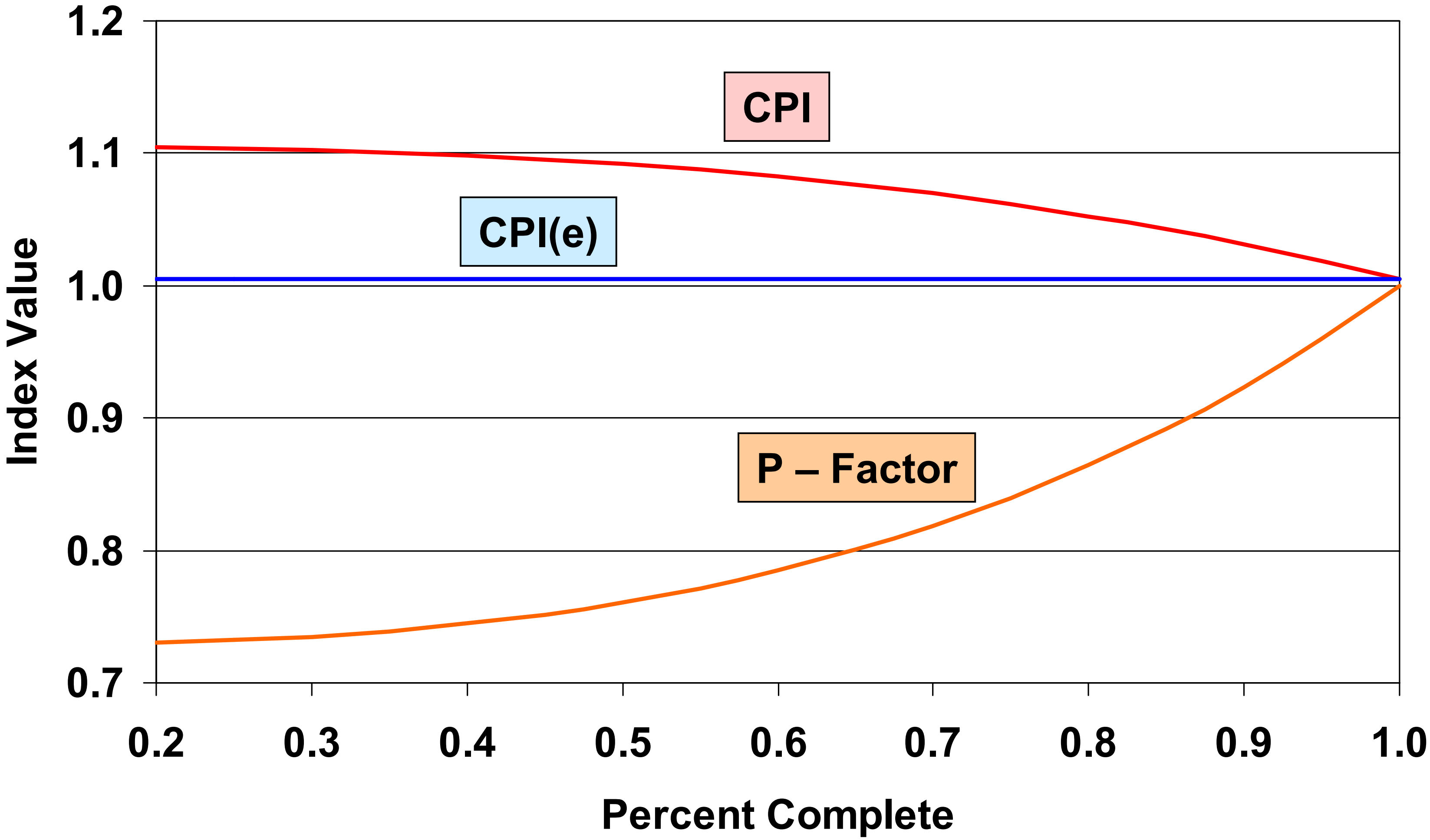
- **Proposed schedule prediction formula:**

IEAC(te) = PD / SPI(te)

Plan Adherence	Comments	Divisor
P ≅ 1.0	Adherence to Schedule	SPI(te) ≅ SPI(t)
P << 1.0	Impediment/Constraint, Poor Process Discipline	SPI(te) < SPI(t)

Conjecture: Neither the P-Factor, nor SPI(t), are likely stable enough to predict duration until the project is 20% complete, similar to the CPI behavior.

Graphs of CPI, CPI(e) & P - Factor (notional data)



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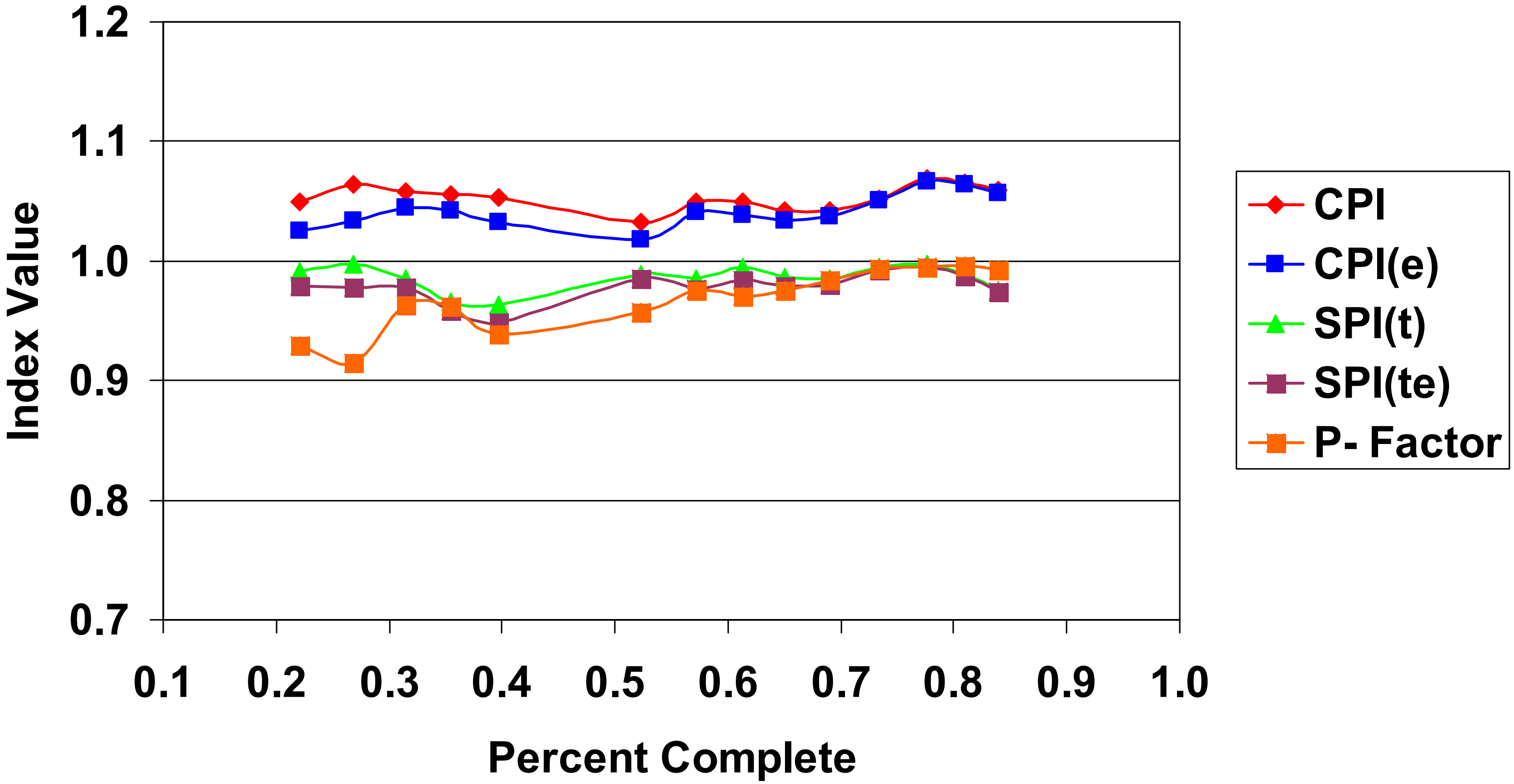
Graphs of CPI & SPI(t) with the P - Factor



Summary

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Summary

- 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
- **Facilitates bridging EVM to the schedule**

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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," ***The Measurable News***, Summer 2003 [Kym Henderson]
- "Further Developments in Earned Schedule," ***The Measurable News***, Spring 2004 [Kym Henderson]
- "Connecting Earned Value to the Schedule," ***The Measurable News***, Pending [Walt Lipke]

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