Earned Schedule Training

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Earned Schedule Training Basic

- EVM Schedule Indicators
- Introduction to Earned Schedule
  - Concept & Metrics
  - Indicators
  - Predictors
  - Terminology

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Earned Schedule Training
Basic

- Application of Concept
  - Analysis & Verification
  - Prediction Comparisons
- Demonstration of ES Calculator
  - V1 & V2 Calculators
- Interpolation Error

Earned Schedule Training
Basic

- *Exercise – Calculate ES, SV(t), SPI(t)*
- Status Update
  - Applications
  - PMI-CPM Earned Value Practice Standard
  - ES Website
- Summary - Basic

Earned Schedule Training Advanced

- Analysis Tool Demonstration
- Re-Baseline Effects
- Critical Path Study
- Network Schedule Analysis
  - Impediments / Constraints
  - Rework

Earned Schedule Training Advanced

- EV Research
  - Schedule Adherence
- Effective Earned Value
  - Derivation
  - Indicators
  - Prediction

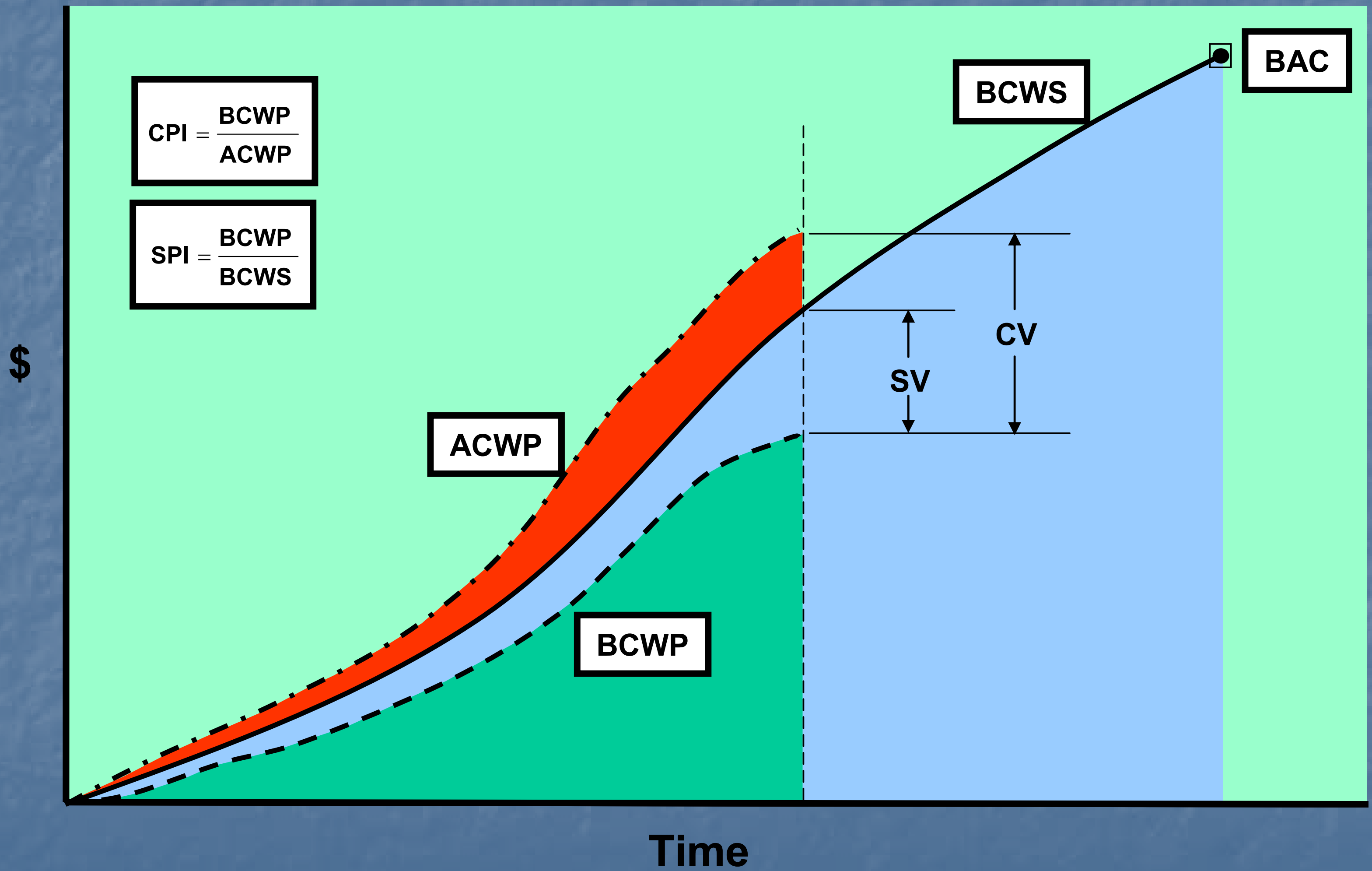
Earned Schedule Training Advanced

- 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



EVM Schedule Indicators

- SV & SPI behave 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

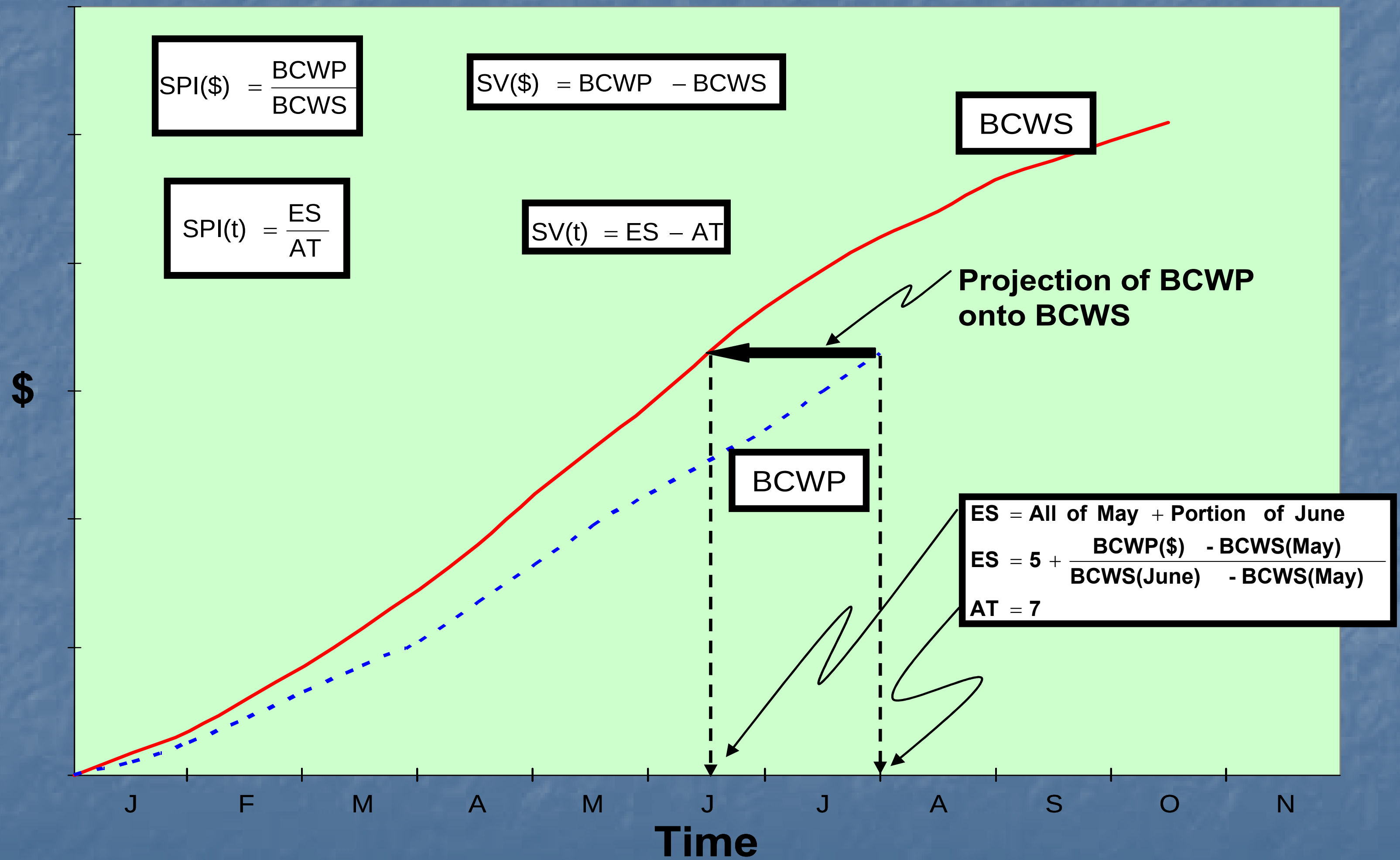
EVM Schedule Indicators

- 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



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_{cum} 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 ≥ BCWS

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

- ESperiod(n) = EScum(n) – EScum(n-1) = ΔES_{cum}
- ATcum
- ATperiod(n) = ATcum(n) – ATcum(n-1) = ΔAT_{cum}

  ΔAT_{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

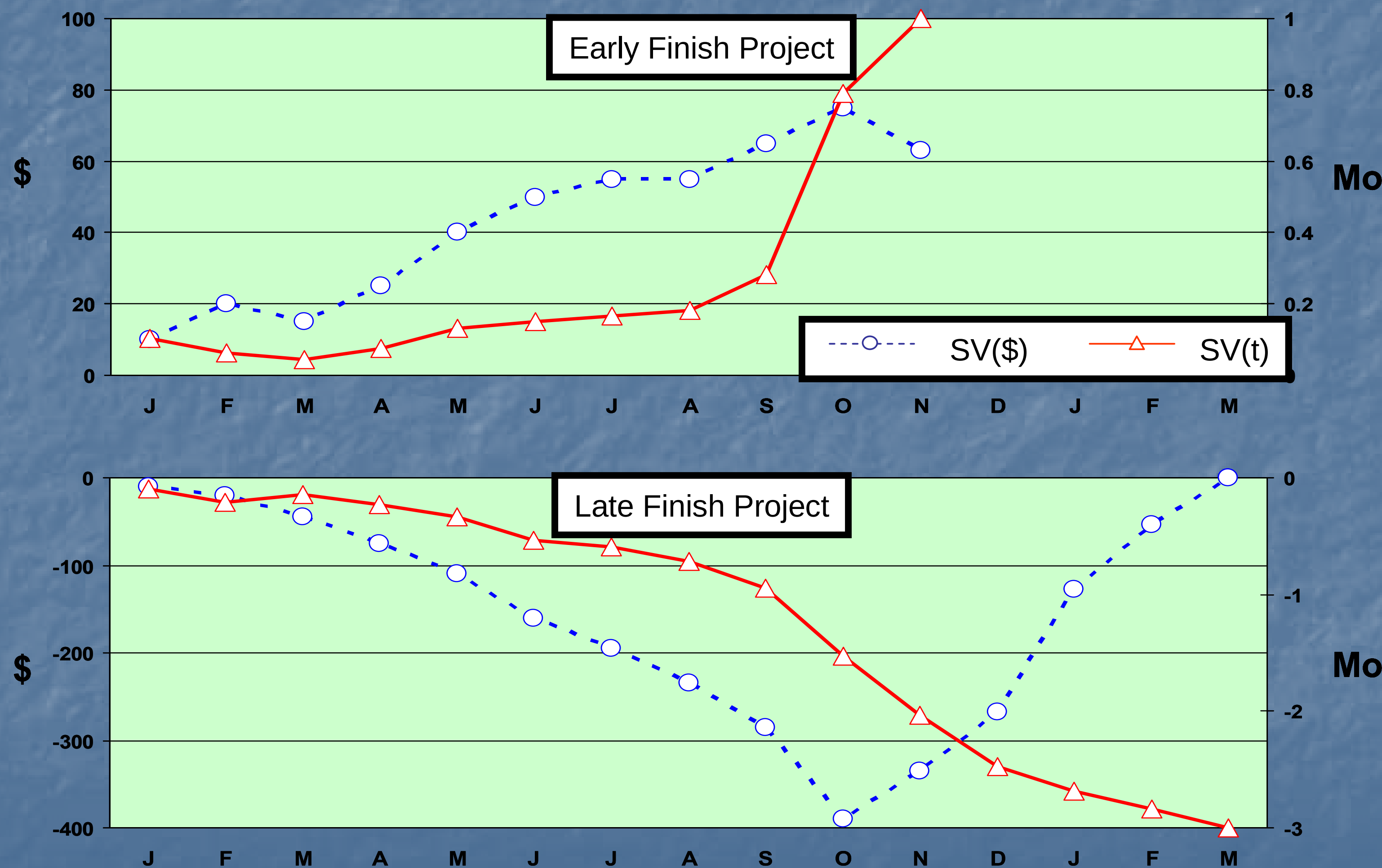
- What happens to the ES indicators, SV(t) & SPI(t), when the planned project duration (PD) is exceeded (BCWS = BAC)?

  They Still Work …Correctly!!

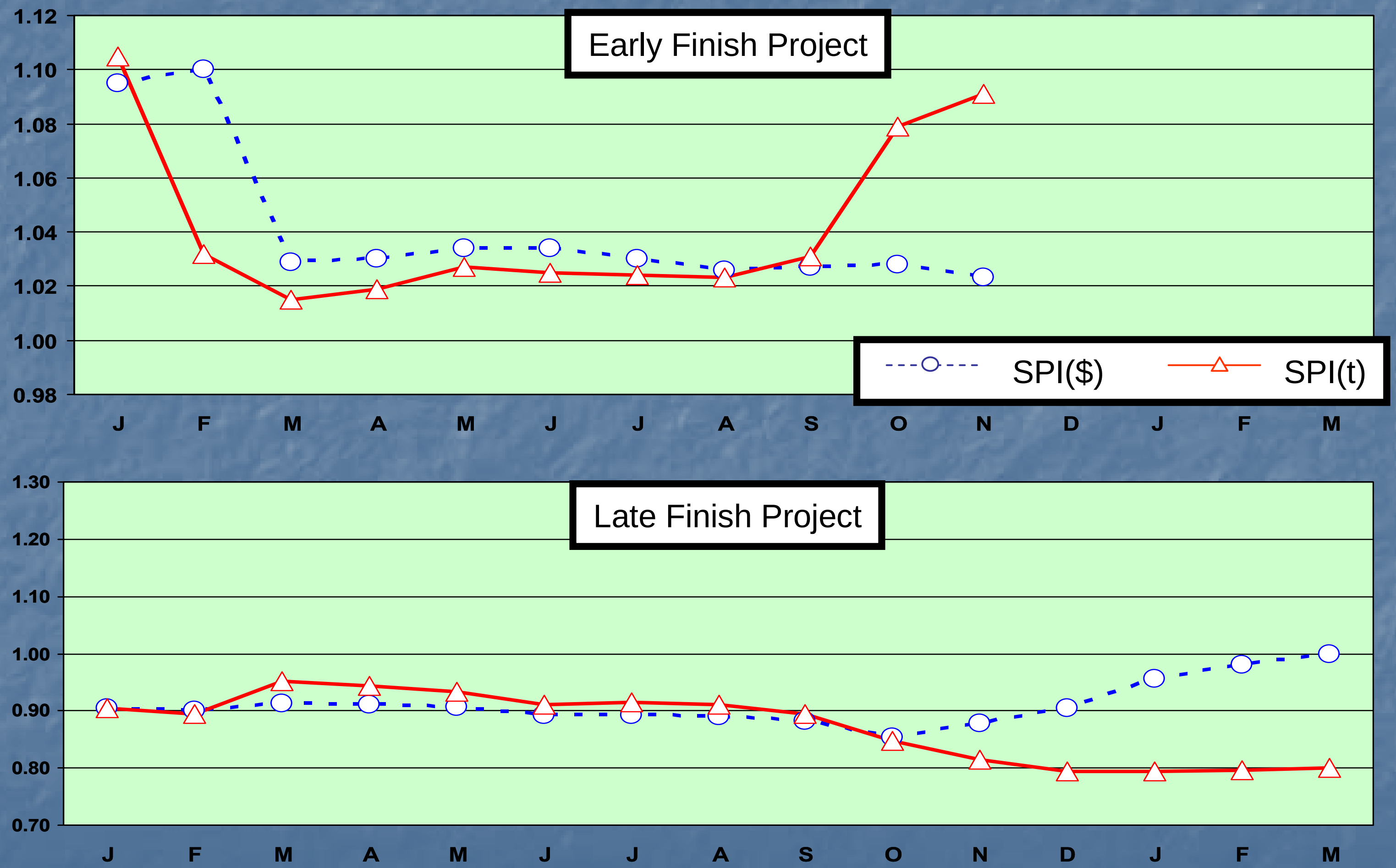
- ES will be ≤ PD, while AT > PD
  - SV(t) will be negative (time behind schedule)
  - SPI(t) will be < 1.00

  Reliable Values from Start to Finish !!

SV Comparison



SPI Comparison



Earned Schedule Predictors

- Can the project be completed as planned?
  - TSPI = Plan Remaining / Time Remaining

    = (PD – ES) / (PD – AT)

    where (PD – ES) = PDWR

    PDWR = Planned Duration for Work Remaining
  - TSPI = (PD – ES) / (ED – AT)

    where ED = Estimated Duration

TSPI Value	Predicted Outcome
≤ 1.00	Achievable
> 1.10	Not Achievable

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)

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Earned Schedule Terminology

	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)

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Earned Schedule Terminology

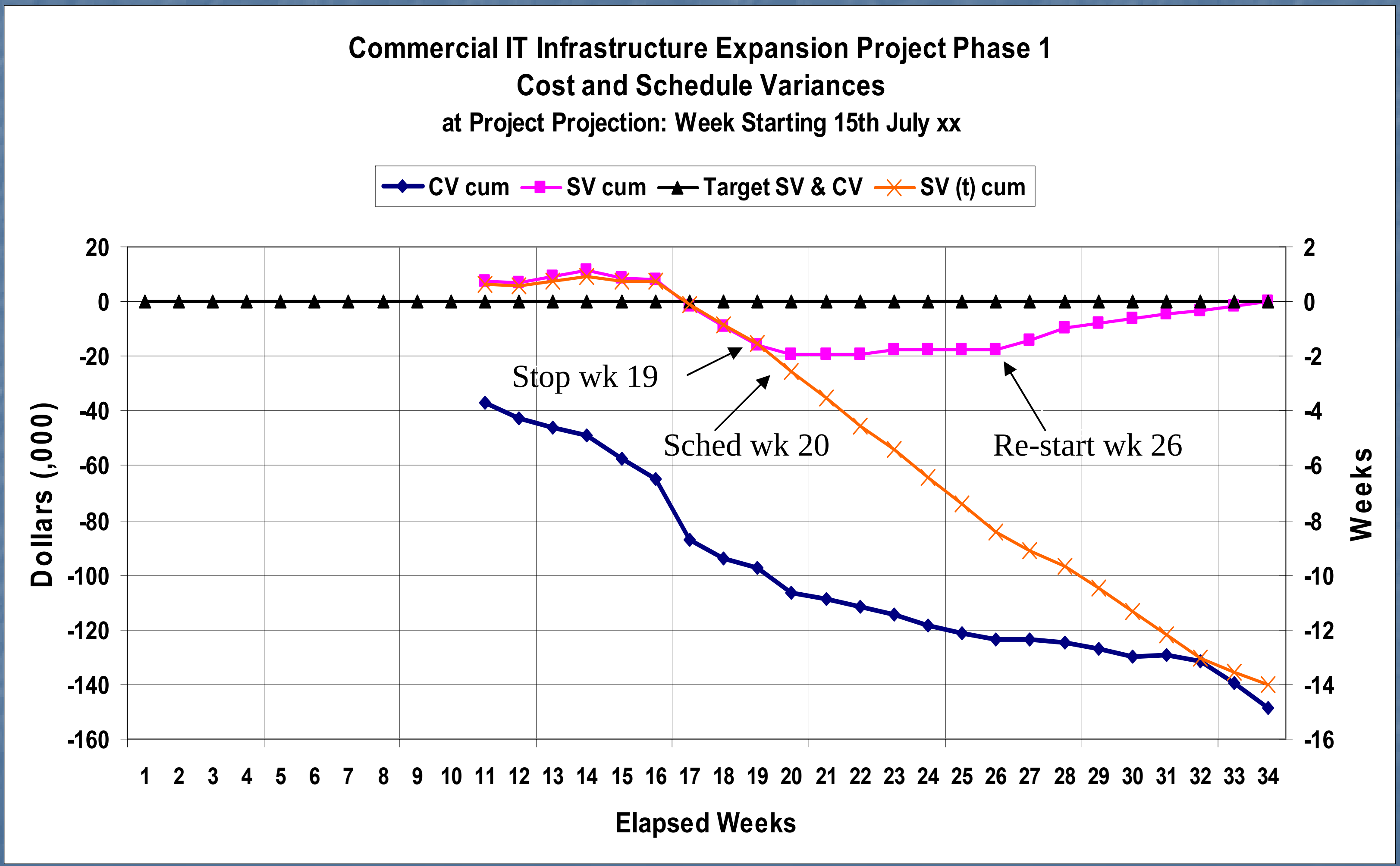
Metrics	Earned Schedule	ES_{cum}	ES = C + I number of complete periods (C) plus an incomplete portion (I)
	Actual Time	AT_{cum}	AT = number of periods executed
Indicators	Schedule Variance	SV(t)	SV(t) = ES - AT
	Schedule Performance Index	SPI(t)	SPI(t) = ES / AT
	To Complete Schedule Performance Index	TSPI(t)	TSPI(t) = (PD – ES) / (PD – AT)
			TSPI(t) = (PD – ES) / (ED – AT)
Predictors	Independent Estimate at Completion (time)	IEAC(t)	IEAC(t) = PD / SPI(t)
			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)

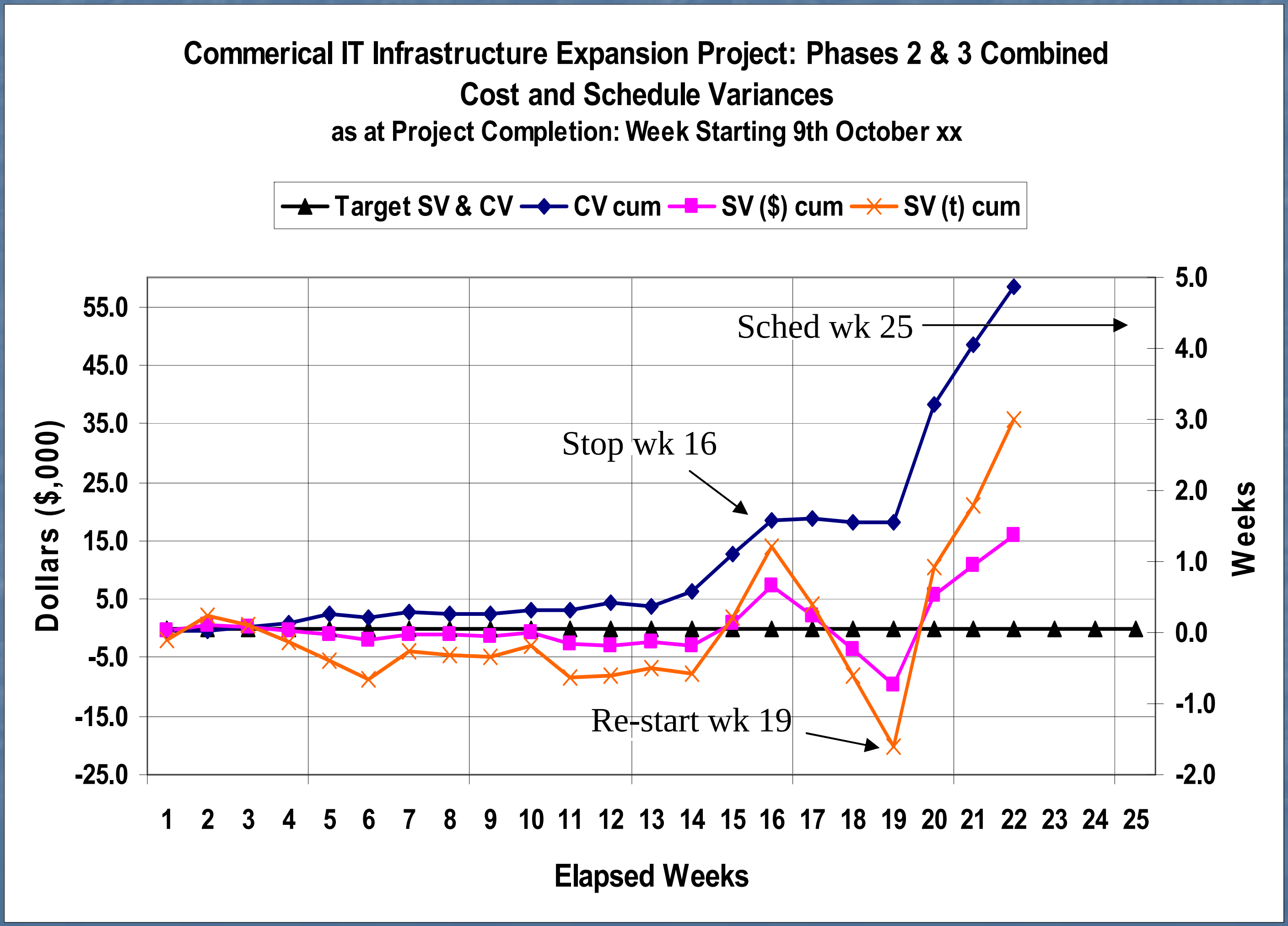
ES Applied to Real Project Data:
Late Finish Project: SV($) and SV(t)



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)



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) = 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**

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

IEAC(t) Prediction Comparison

Early and Late Finish Project Examples

IEAC(t) Metrics at Project Completion Early Finish Project	
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($) cum	1.00
Critical Ratio cum	0.52
IEAC(t) PD/SPI(t) cum	34.0
IEAC(t) PD/SPI($) cum	20.0
IEAC(t) PD/ 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 *(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

IEAC(t) Predictions using ES Techniques:
Same *Early and Late Finish Project Examples*

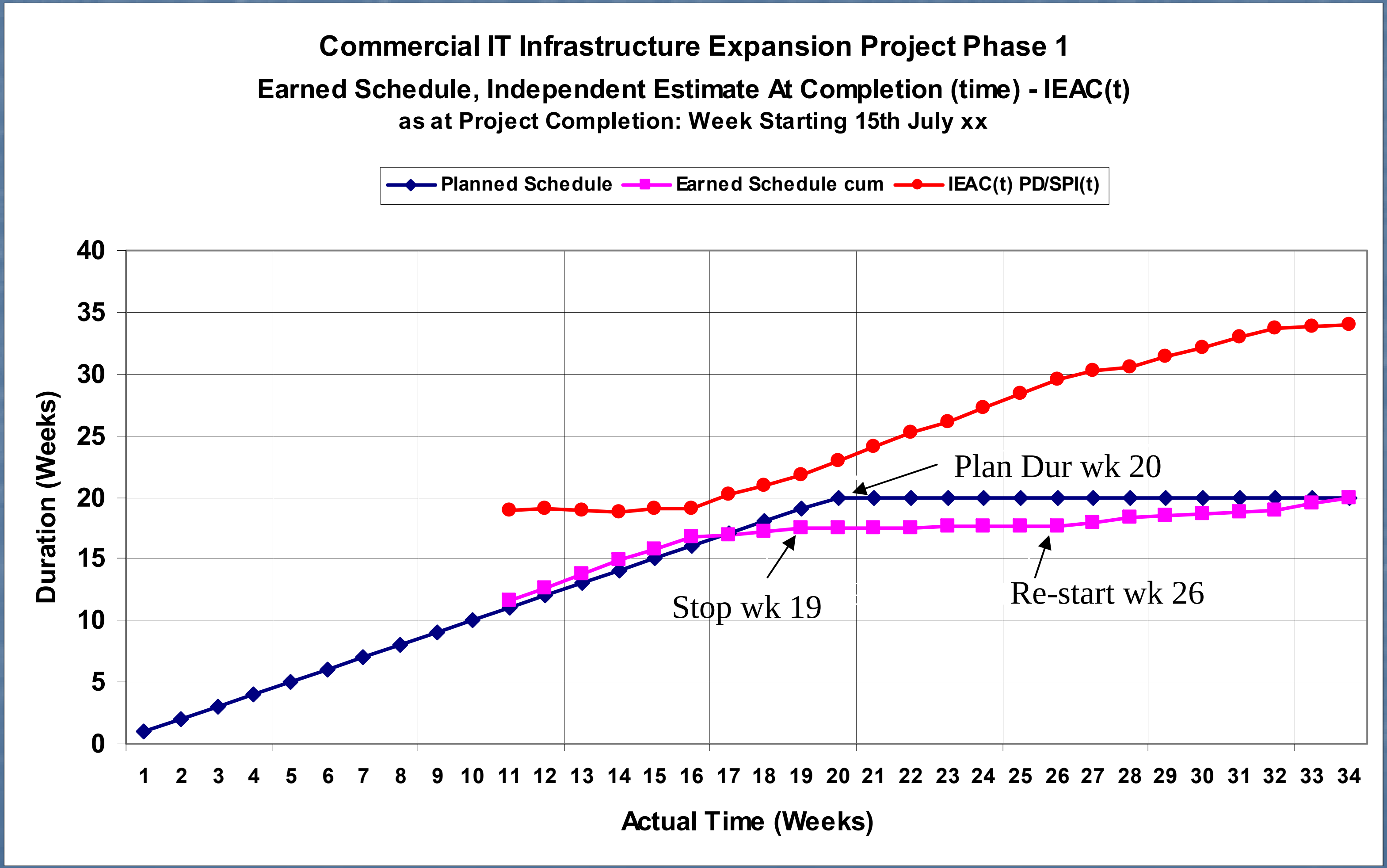
IEAC(t) Metrics at Project Completion Early Finish Project using ES	
Planned Duration (weeks)	25
Actual Time (weeks)	22
Earned Schedule cum	25.0
Planned Duration Work Remaining	0.0
Percentage Complete cum	100%
CPI cum	2.08
SPI(t) cum	1.14
SPI($) cum	1.17
Critical Ratio cum	2.43
Critical Ratio ES cum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

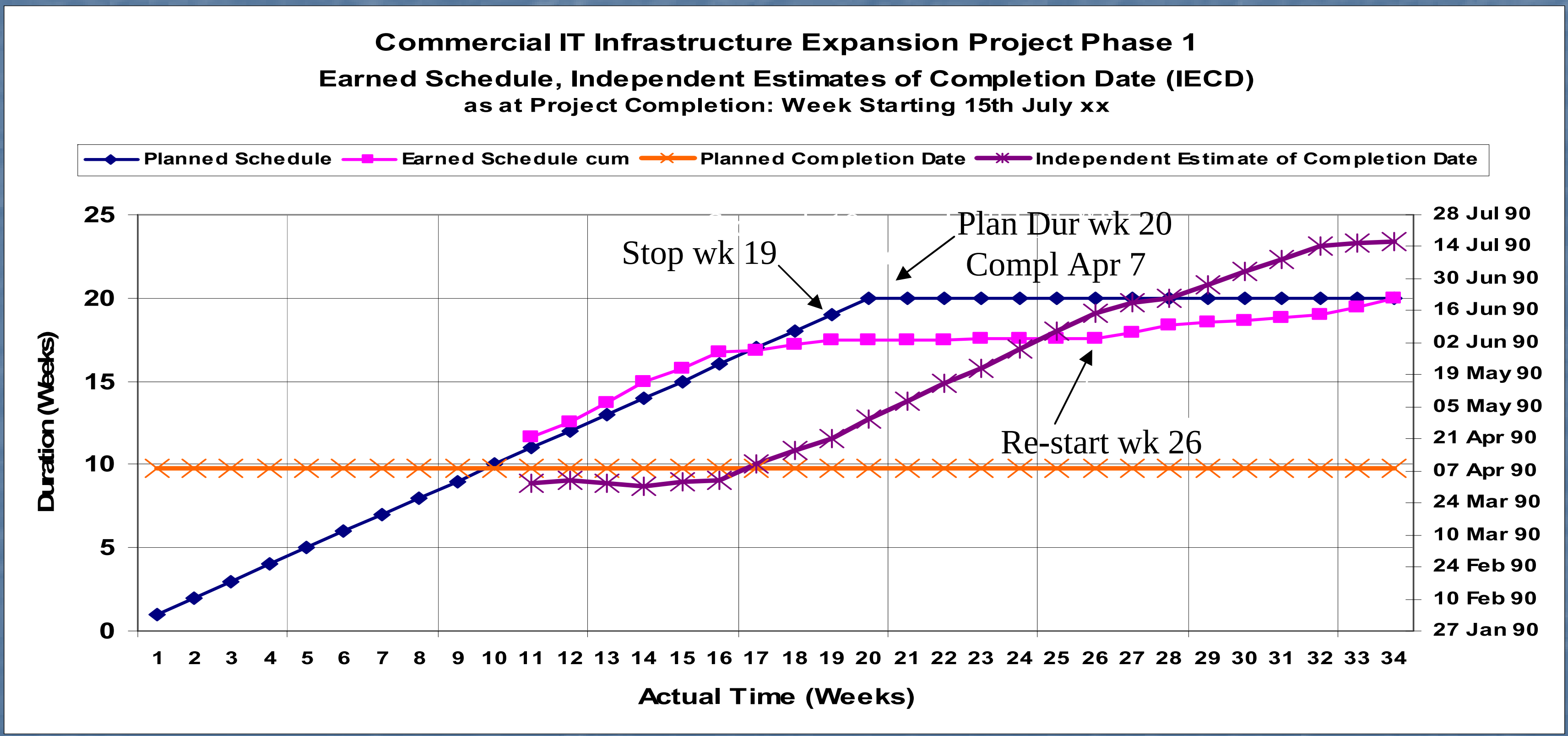
- Use of the ES "long form" IEAC(t) formula, results in **correct** calculation of Actual Duration at Completion

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

- **ES formulae and results are algebraically correct**

> *"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."*

- Kym Henderson

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]

[1] Lipke Walt, Schedule is Different, The Measurable News, Summer 2003

[2] Henderson Kym, Earned Schedule: A Breakthrough Extension to Earned Value Theory? A Retrospective Analysis of Real Project Data,The Measurable News, Summer 2003

[3] Henderson, Kym, Further Development in Earned Schedule,The Measurable News, Spring 2004

Demonstration of Earned Schedule Calculator

Earned Schedule Calculator

Earned Schedule Calculator (V1)

Earned Schedule Calculator

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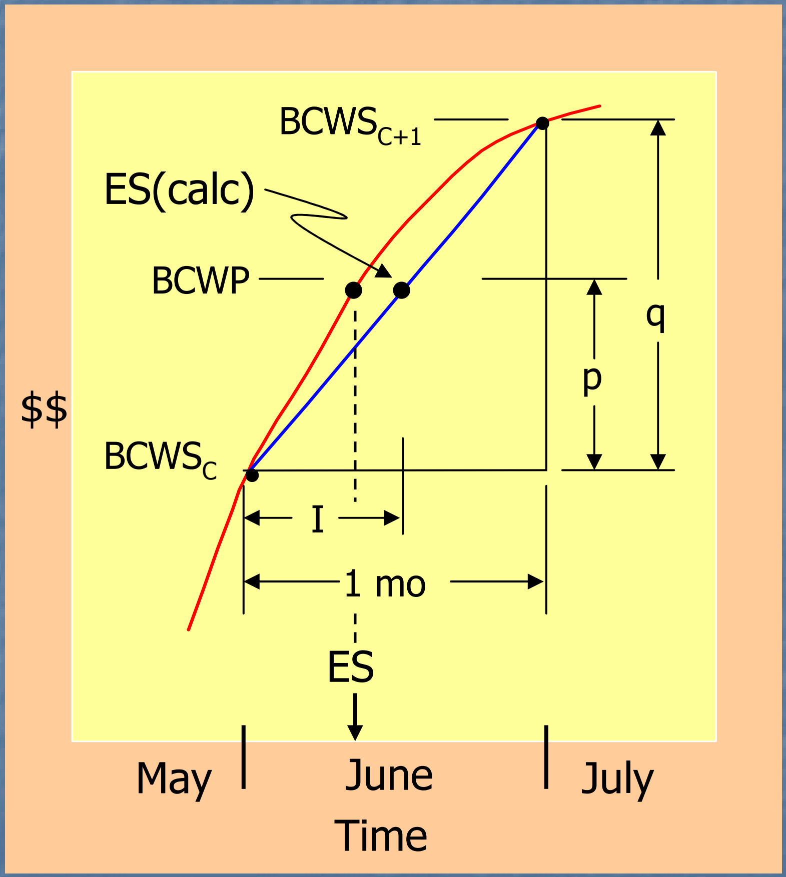
Earned Schedule Calculator (V2)

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



$I / 1\text{ mo} = p / q$

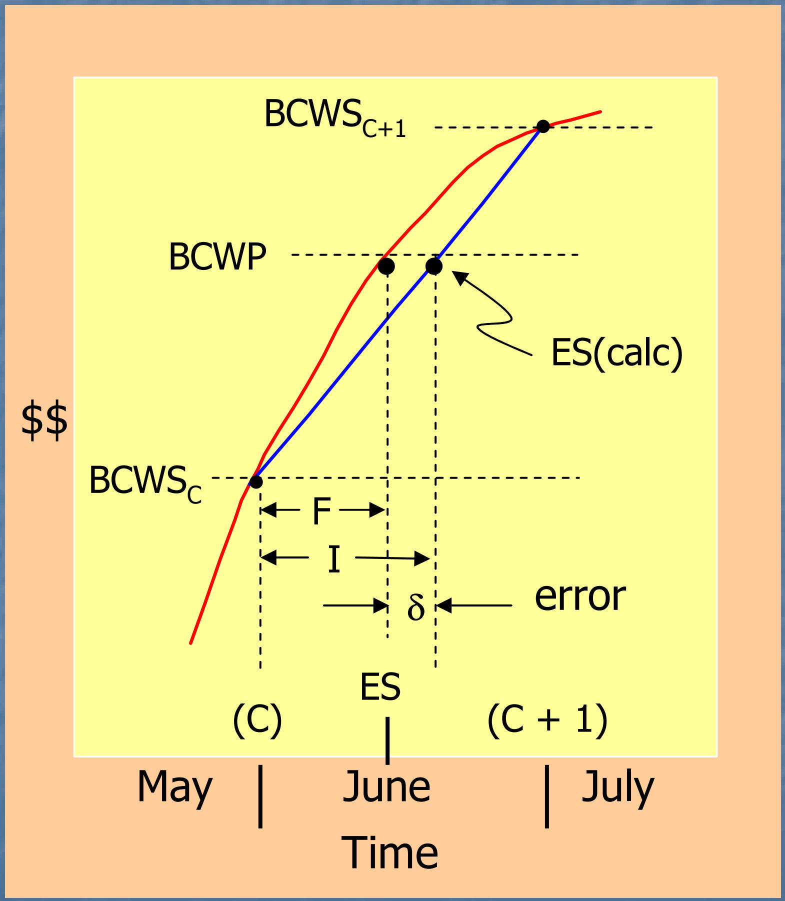
$I = (p / q) * 1\text{ mo}$

$p = BCWP - BCWS_C$

$q = BCWS_{C+1} - BCWS_C$

$$I = \frac{BCWP - BCWS_C}{BCWS_{C+1} - BCWS_C} * 1\text{mo}$$

Interpolation Error



ES = Number of whole months (C) + Increment on curve (F)

= C + F

ES(calc) = C + calculated increment (I)

Error (δ) = I - F

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

Example = .05 / 8.12 = 0.6%

As C ⇒ larger

- % error ⇒ smaller
- ES(calc) ⇒ more accurate

Weekly EV make ES more accurate

Interpolation Error

- After a few months of status (C > 4) - interpolation error is negligible (≤ 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

BREAK – 15 Minutes

Exercise – *Calculate ES, SV(t), SPI(t)*

Exercise # 1

- Complete Early & Late Worksheets (tan areas <u>only</u>):

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

ES Exercise - Worksheet

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
BSWS($)	105	200	515	845	1175	1475	1805	2135	2435	2665	2760	2823
BCWP($)	115	220	530	870	1215	1525	1860	2190	2500	2740	2823	------
SV($)	10	20	15	25	40	50	55	55	65	75	63	------
SPI($)	1.095	1.100	1.029	1.030	1.034	1.034	1.030	1.026	1.027	1.028	1.023	------

Month Count	1	2	3	4	5	6	7	8	9	10	11	12
ES(cum)												
SV(t)												
SPI(t)												

Early Finish Project (Cumulative Values)

ES Exercise - Worksheet

	Year 01												Year 02		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
BSWS($)	105	200	515	845	1175	1475	1805	2135	2435	2665	2760	2823	------	------	------
BCWP($)	95	180	470	770	1065	1315	1610	1900	2150	2275	2425	2555	2695	2770	2823
SV($)	-10	-20	-45	-75	-110	-160	-195	-235	-285	-390	-335	-268	-128	-53	0
SPI($)	0.905	0.900	0.913	0.911	0.906	0.892	0.892	0.890	0.883	0.854	0.879	0.905	0.955	0.981	1.000

Month Count	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ES(cum)															
SV(t)															
SPI(t)															

Late Finish Project (Cumulative Values)

ES Exercise - Answers

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
BSWS($)	105	200	515	845	1175	1475	1805	2135	2435	2665	2760	2823
BCWP($)	115	220	530	870	1215	1525	1860	2190	2500	2740	2823	------
SV($)	10	20	15	25	40	50	55	55	65	75	63	------
SPI($)	1.095	1.100	1.029	1.030	1.034	1.034	1.030	1.026	1.027	1.028	1.023	------

Month Count	1	2	3	4	5	6	7	8	9	10	11	12
ES(mo)	1.105	2.063	3.045	4.076	5.133	6.152	7.167	8.183	9.283	10.789	12.000	------
SV(t)	0.105	0.063	0.045	0.076	0.133	0.152	0.167	0.183	0.283	0.789	1.000	------
SPI(t)	1.105	1.032	1.015	1.019	1.027	1.025	1.024	1.023	1.031	1.079	1.091	------

Early Finish Project (Cumulative Values)

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ES Exercise - Answers

	Year 01												Year 02		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
BSWS($)	105	200	515	845	1175	1475	1805	2135	2435	2665	2760	2823	------	------	------
BCWP($)	95	180	470	770	1065	1315	1610	1900	2150	2275	2425	2555	2695	2770	2823
SV($)	-10	-20	-45	-75	-110	-160	-195	-235	-285	-390	-335	-268	-128	-53	0
SPI($)	0.905	0.900	0.913	0.911	0.906	0.892	0.892	0.890	0.883	0.854	0.879	0.905	0.955	0.981	1.000

Month Count	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ES(mo)	0.905	1.789	2.857	3.772	4.667	5.547	6.409	7.288	8.050	8.467	8.967	9.522	10.316	11.159	12.000
SV(t)	-0.095	-0.211	-0.143	-0.228	-0.333	-0.533	-0.591	-0.712	-0.950	-1.533	-2.033	-2.478	-2.684	-2.841	-3.000
SPI(t)	0.905	0.894	0.952	0.943	0.933	0.911	0.916	0.911	0.894	0.847	0.815	0.794	0.794	0.797	0.800

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
- 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

PMI-CPM EVM Practice Standard

- Inclusion of Emerging Practice Insert into PMI - EVM Practice Standard
  - Dr. John Singley, VP of CPM
- Included in Box 3-1 of EVM Practice Standard
  - Describes basic principles of "Earned Schedule"
  - Provides foundation for 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

Available Resources

- PMI-Sydney http://sydney.pmichapters-australia.org.au/
  - Repository for ES Papers and Presentations
- Earned Schedule Website http://www.earnedschedule.com/
  - Established February 2006
  - Contains *News, Papers, Presentations, ES Terminology, ES Calculators*
  - Identifies Contacts to assist with application
- Wikipedia now references Earned Schedule http://en.wikipedia.org/wiki/Earned_Schedule

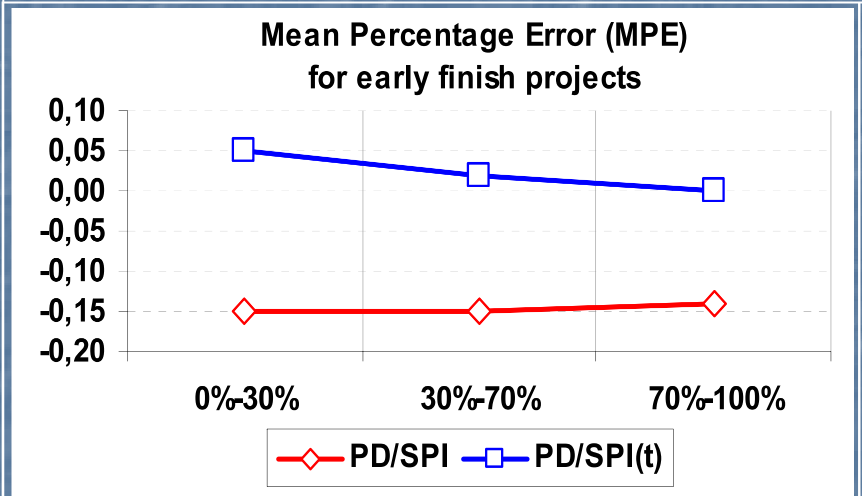
Foreseen Uses of Earned Schedule

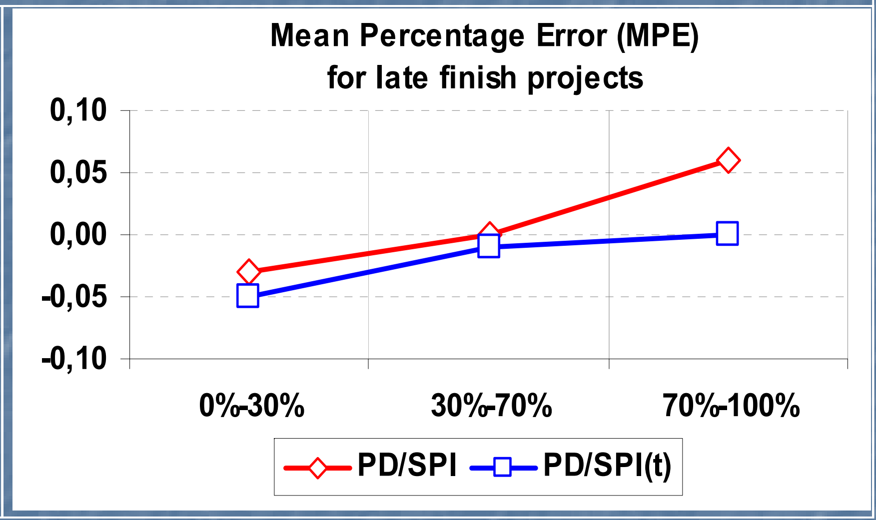
- Enables independent evaluation of schedule estimates: ETC(t), EAC(t)
  - Client, Contractor, Program and Project Manager ….
- Facilitates insight into network schedule performance
  - Duration based Schedule indicators
  - Identification of impediments/constraints and potential future rework
  - Evaluation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

3 Research Efforts (2/3)

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





Plans 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.

[8] Vanhoucke Mario, Vandevoorde Stephan, A simulation and evaluation of earned value metrics to forecast the project duration , Working Paper 2005/317, July 2005, Ghent University

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

BREAK – 15 Minutes

Earned Schedule Training
Advanced

Analysis Tool Demonstration

www.earnedschedule.com

Earned Schedule Analysis Tool

Earned Schedule
Analysis Tool

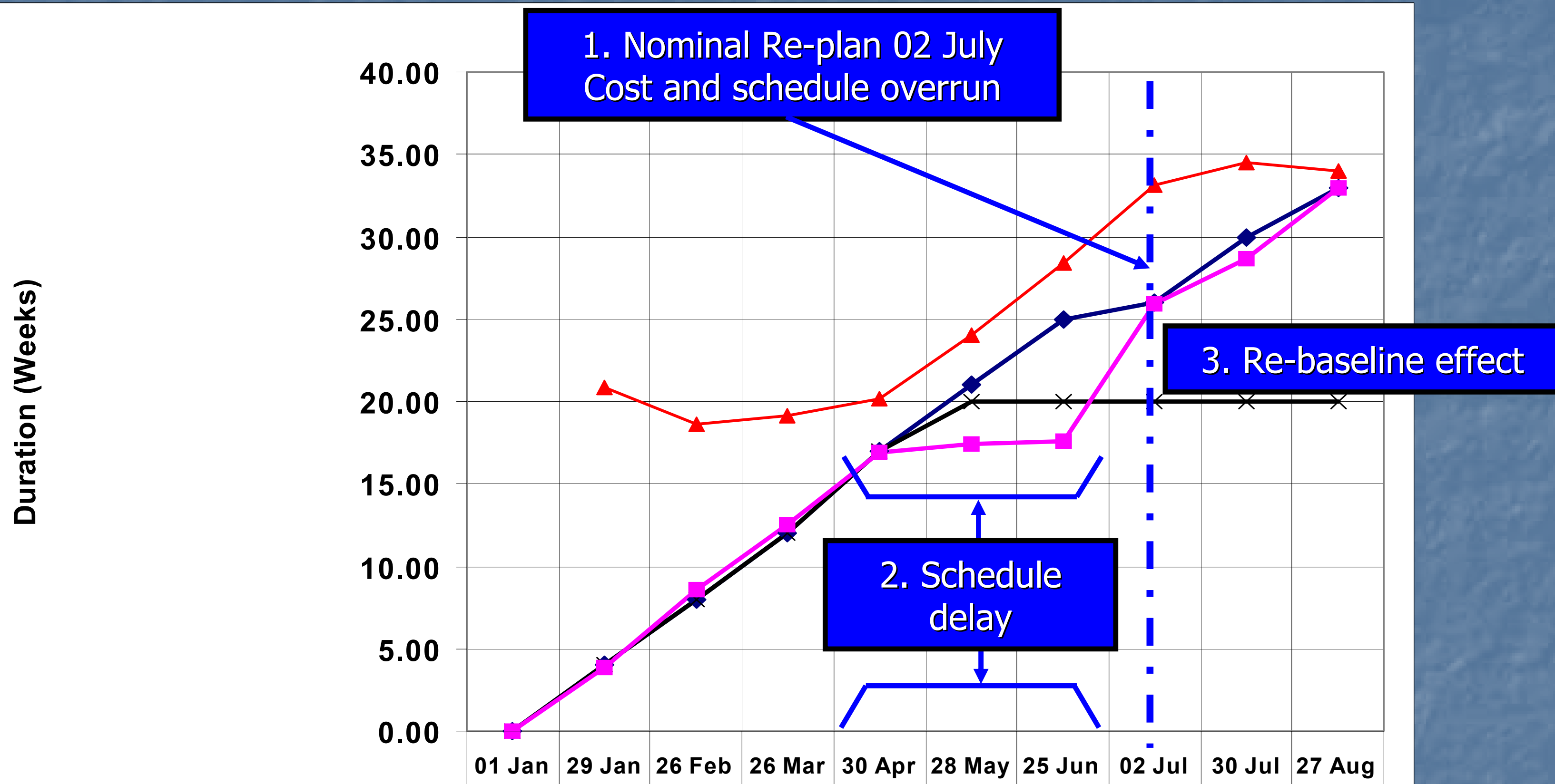
ES and Re-Baselining

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

Earned Schedule – Re-Baseline Example

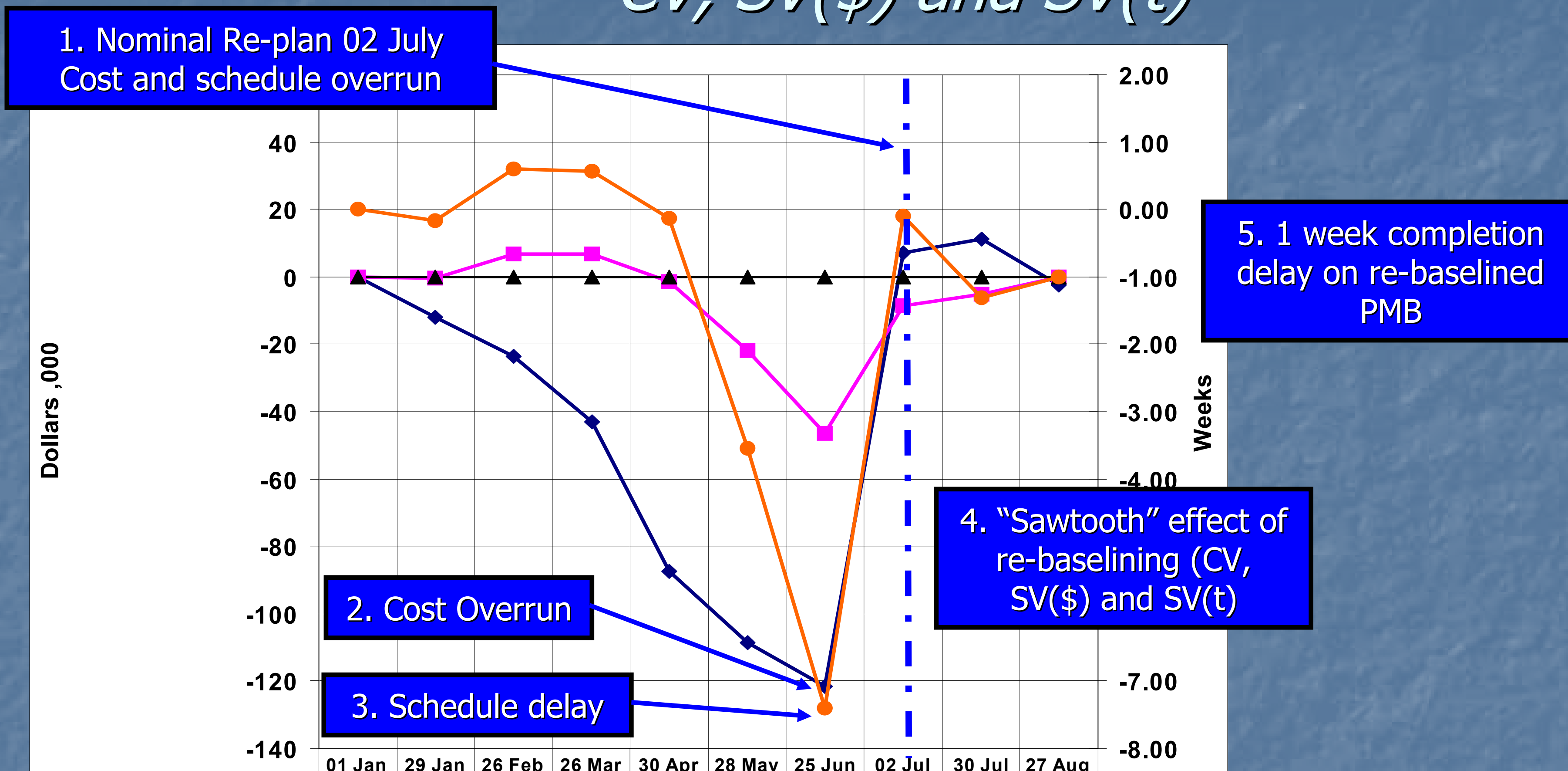
Real project data – nominal re-baseline



	01 Jan	29 Jan	26 Feb	26 Mar	30 Apr	28 May	25 Jun	02 Jul	30 Jul	27 Aug
Actual Time (weeks)	0.00	4.00	8.00	12.00	17.00	21.00	25.00	26.00	30.00	34.00
Planned Schedule ReBline #1	0.00	4.00	8.00	12.00	17.00	21.00	25.00	26.00	30.00	33.00
Planned Schedule cum CBB	0.00	4.00	8.00	12.00	17.00	20.00	20.00	20.00	20.00	20.00
Earned Schedule cum	0.00	3.84	8.60	12.56	16.87	17.45	17.59	25.91	28.70	33.00
IEAC(t) SPI(t)		20.85	18.60	19.11	20.15	24.07	28.42	33.12	34.50	34.00

Earned Schedule – Re-Baseline Example

CV, SV($) and SV(t)



	01 Jan	29 Jan	26 Feb	26 Mar	30 Apr	28 May	25 Jun	02 Jul	30 Jul	27 Aug
Actual Time (weeks)	0.00	4.00	8.00	12.00	17.00	21.00	25.00	26.00	30.00	34.00
CV cum	0.00	(12.14)	(23.70)	(42.92)	(87.31)	(108.61)	(121.43)	6.96	11.09	(2.30)
SV($) cum	0.00	(0.41)	6.65	6.73	(1.42)	(22.07)	(46.48)	(8.60)	(5.22)	0.00
Target CV and SV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SV(t) cum	0.00	(0.16)	0.60	0.56	(0.13)	(3.55)	(7.41)	(0.09)	(1.30)	(1.00)

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

The Scheduling Challenge

- 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
- <u>Integration</u>
  - Of schedules between "master" and "subordinate" schedules
  - Often across multiple tiers of
    - Activities and
    - Organisations

    contributing to the overall program of work
- <u>Essential</u> for producing a <u>useful</u> 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

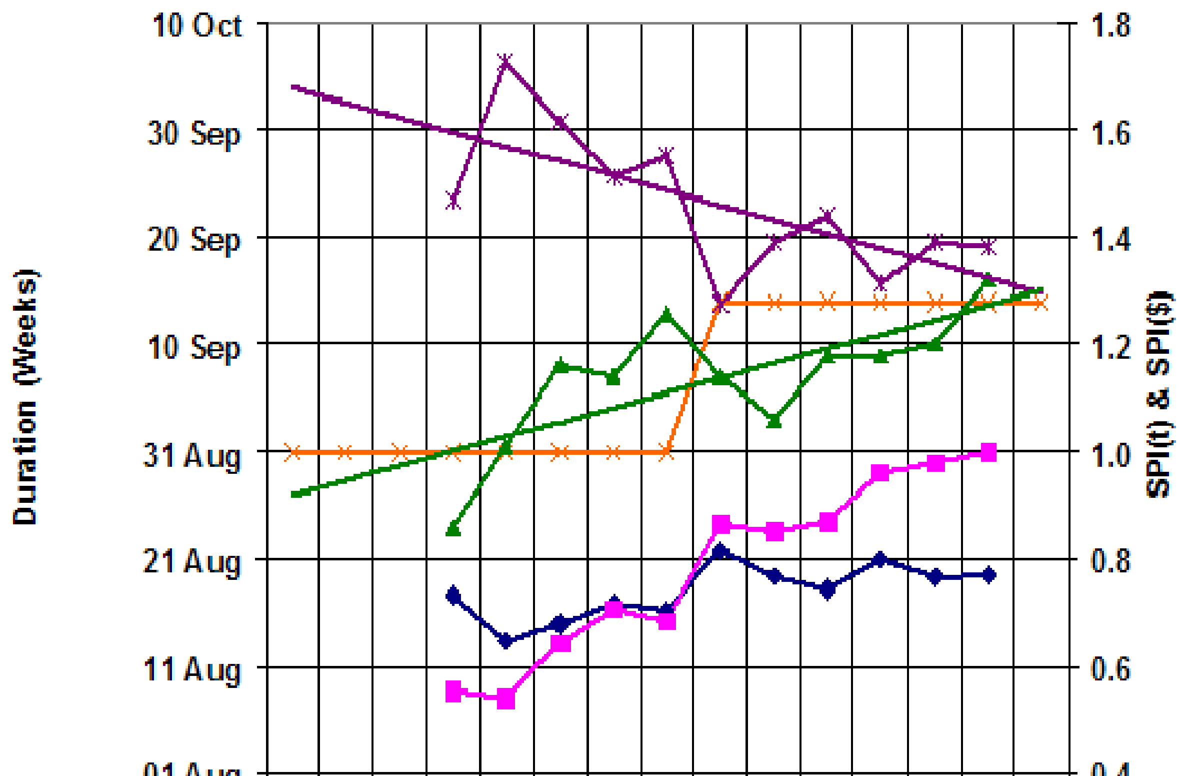
Schedule Management

- 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



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Planned Completion Date	31	31	31	31	31	31	31	31	14	14	14	14	14	14	14
ECD (PD/SPI(t))				23	08 Oct	30	26	27	13	19	21	16	19	19	
Critical Path Completion				24	31	08	07	13	07	03	09	09	10	16	
SPI(t) cum				0.73	0.65	0.68	0.72	0.70	0.82	0.77	0.74	0.80	0.77	0.77	
SPI($) cum				0.56	0.54	0.64	0.71	0.69	0.87	0.86	0.87	0.96	0.98	1.00	

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 <u>this circumstance</u>
  - 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
  - <u>The same as EVM for cost</u>
- 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

Network Schedule Analysis

Schedule Analysis with EVM?

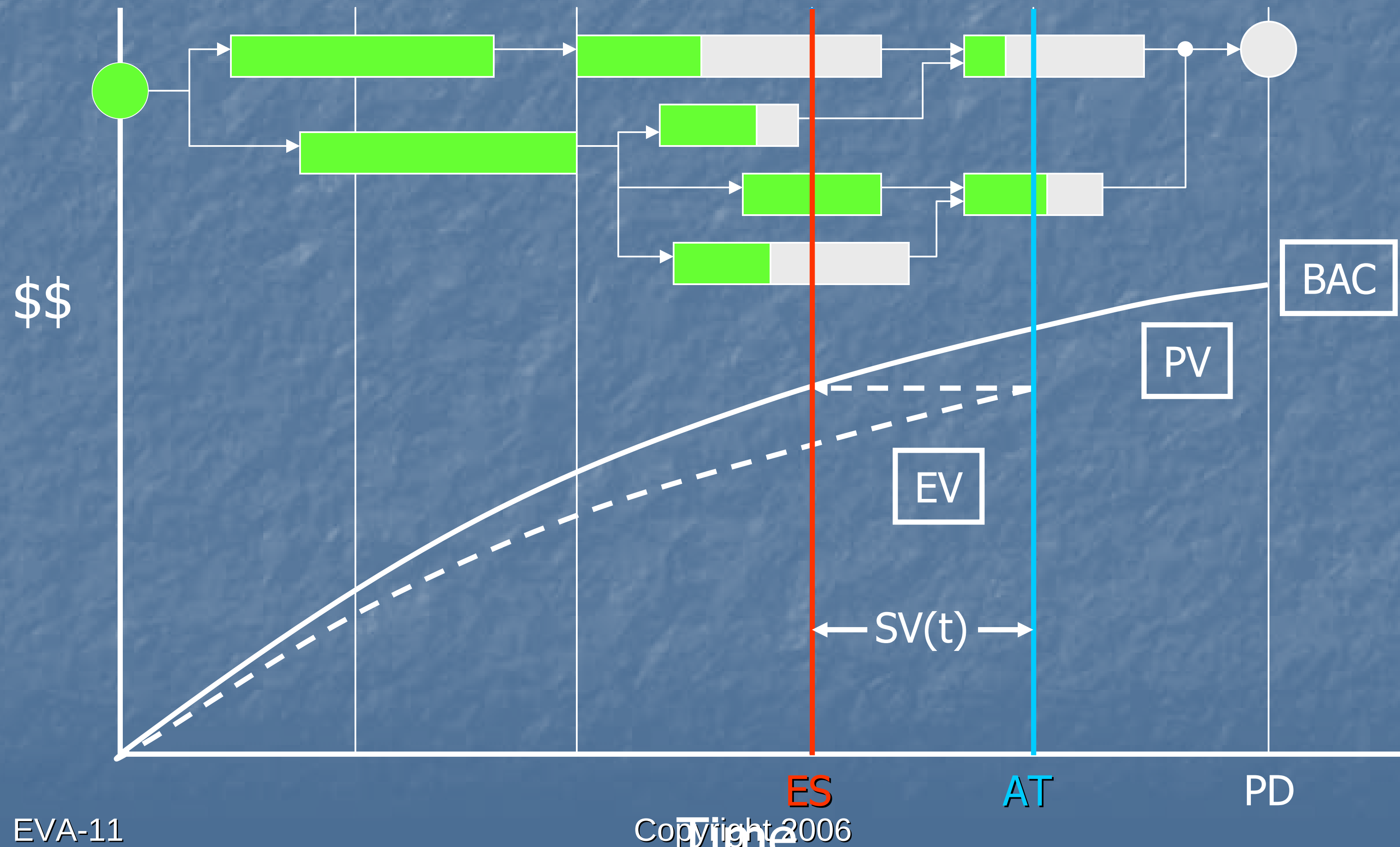
- The general belief is EVM cannot be used to predict schedule duration
- Most practitioners analyze schedule from the bottom up using the networked schedule ….“It is the only way possible.”
  - Analysis of the Schedule is overwhelming
  - Critical Path is used to shorten analysis
    (CP is longest 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



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!!

BREAK – 15 Minutes

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 $\Rightarrow$ BAC
  - $|CPI(final) – CPI(20\%)| \leq 0.10$
  - IEAC = BAC / CPI $\leq$ Final Cost

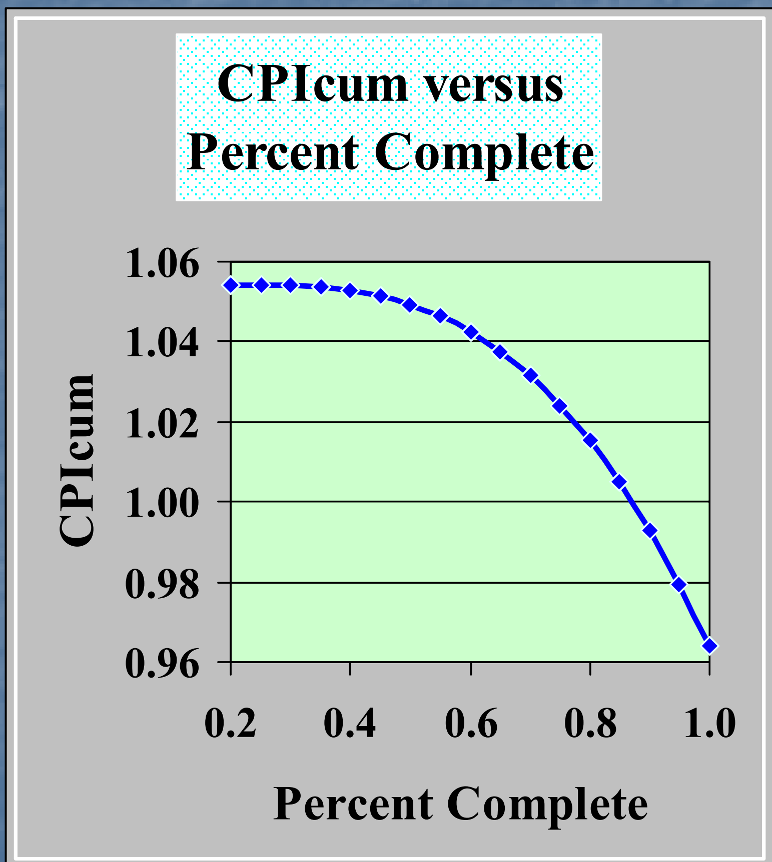
when Percent Complete is 20% $\Leftrightarrow$ 70%

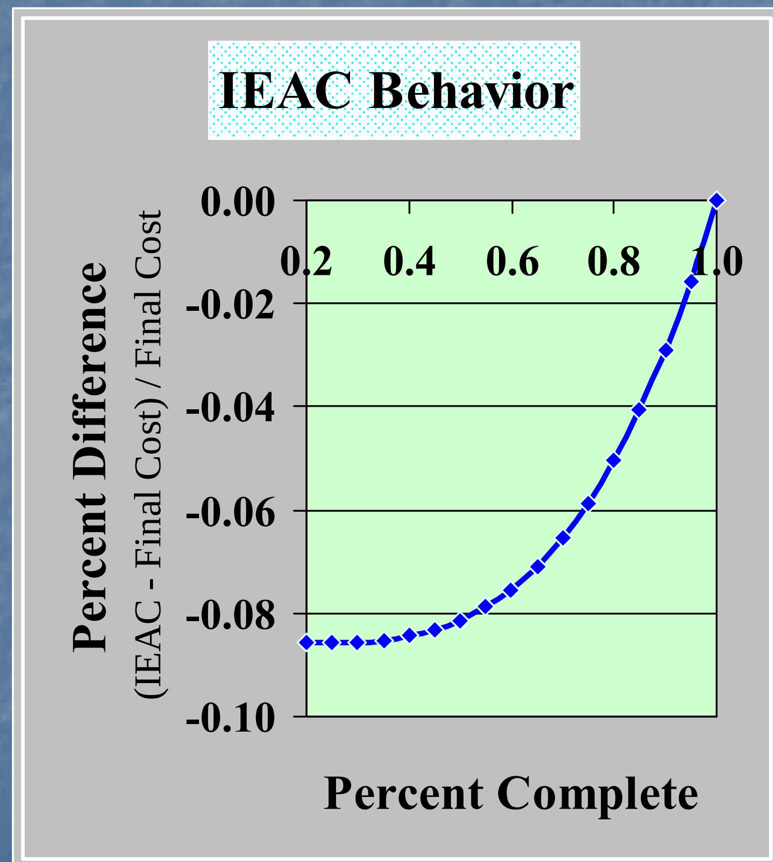
Discussion of EV Research

- 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





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 $\Rightarrow$ BAC

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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:*

$$P = \text{Tasks (perf - corr)} / \text{Tasks (plan)}$$

$$= \Sigma\, EVj\ (\text{corresponding}) / \Sigma\, PVj\ (\text{plan})$$

$$\text{where } \Sigma\, EVj \leq \Sigma\, PVj \quad \& \quad \Sigma\, PVj = EV$$

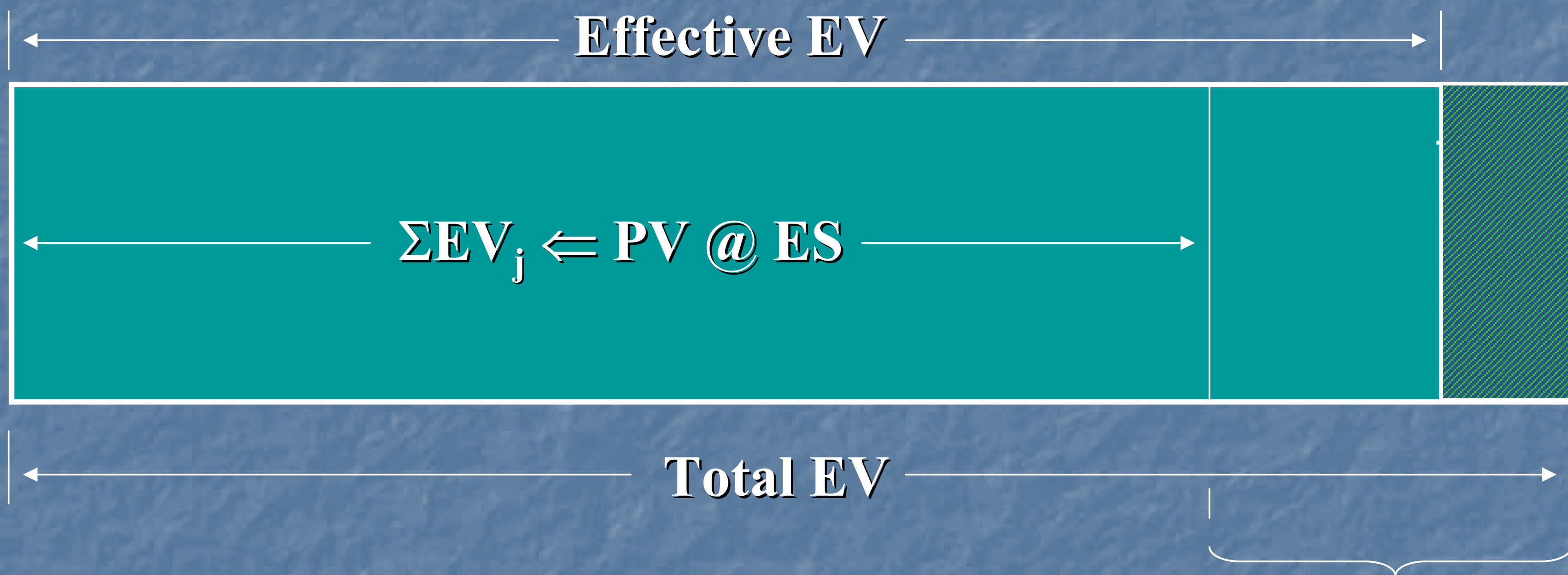
Schedule Adherence

- 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



EV(r)

EV(r) is performed at risk of creating rework
Portion colored [teal] is usable
Portion colored [hatched] is unusable

Effective EV Relationships

- P-Factor (or P) = ΣEVj / ΣPVj = ΣEVj / EV
  - $\Sigma EVj = P * EV$
- EV(p) is portion of EV consistent with the plan
  - $EV(p) = \Sigma EVj = P * EV$
- EV(r) is portion of EV with anticipated rework
  - $EV(r) = EV – EV(p) = EV – P * EV$
  - $EV(r) = (1 – P) * EV$

Effective EV Relationships

- Rework proportion (R%) = f(r) / f(p)

  f(r) = fraction of EV(r) unusable

  f(p) = fraction of EV(r) usable

  f(r) + f(p) = 1

- Portion of EV(r) usable

  f(p) ∗ R% + f(p) = 1

  f(p) = 1 / (1 + R%)

Effective Earned Value

- Effective earned value is a function of EV, P, and Rework: **EV(e) = f (EV, P, Rework)**

  $EV(e) = EV(p) + (\text{fraction usable}) * EV(r)$

  $= P * EV + (1 / 1 + R\%) * [(1 – P) * EV]$
- General equation for Effective Earned Value

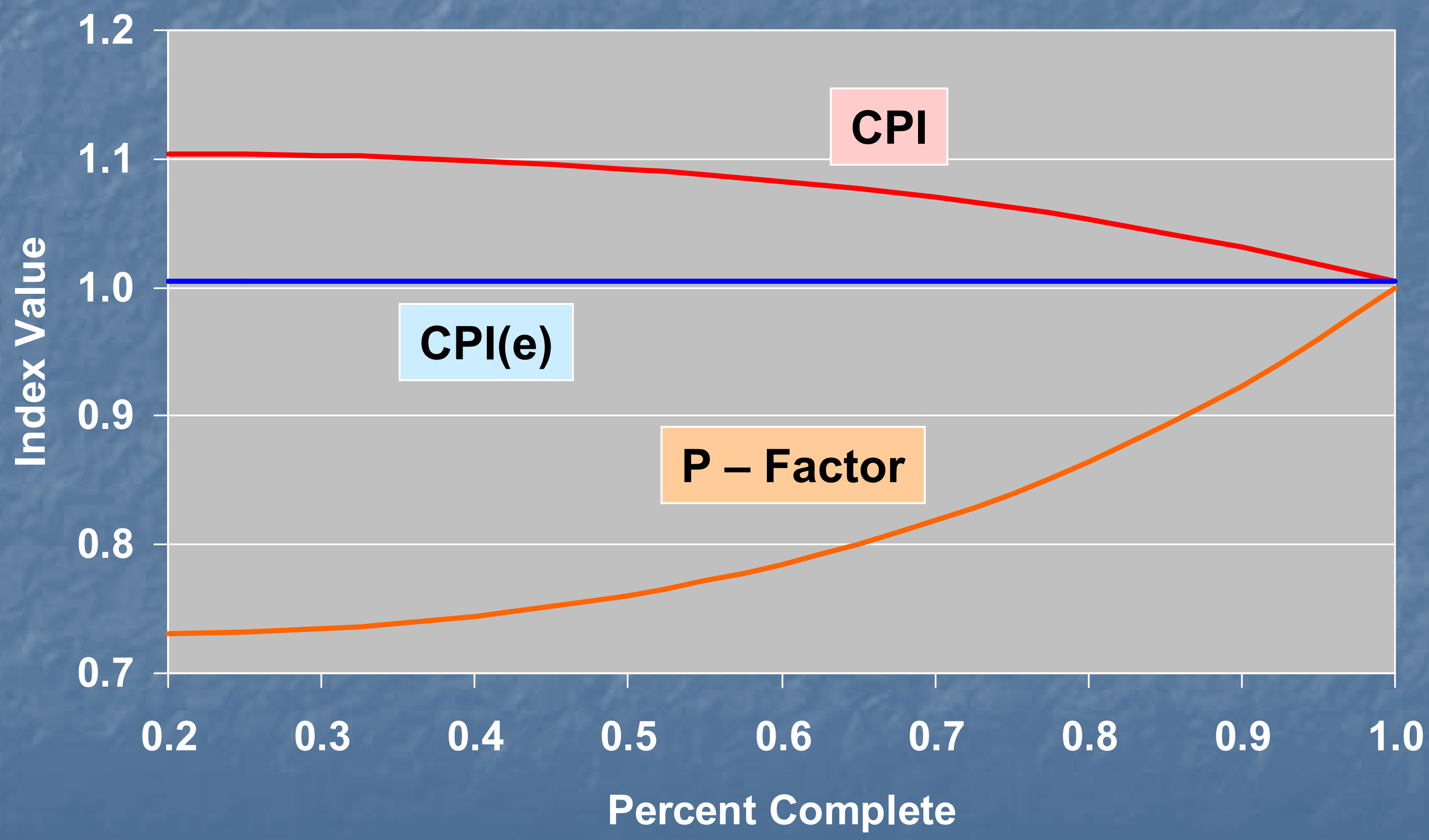
  $$EV(e) = [(1 + P * R\%) / (1 + R\%)] * EV$$
- Special case, when R% = 50%

  $$EV(e) = [(P + 2) / 3] * EV$$

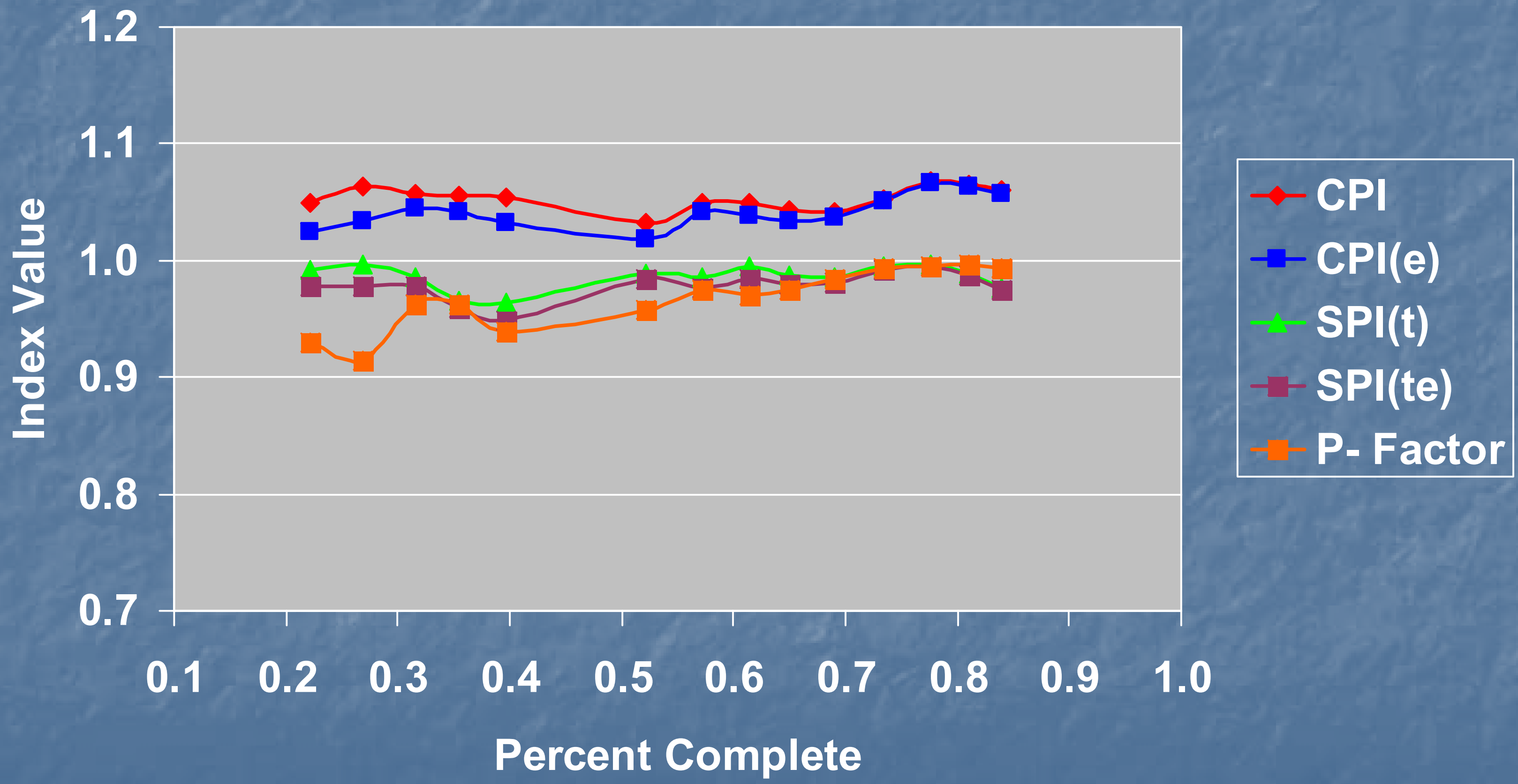
Effective Earned Value

- Effective ES is computed using EV(e)
  {i.e., ES(e)}
- Effective EV and ES indicators are …
  - CV(e) = EV(e) – AC
  - CPI(e) = EV(e) / AC
  - SV(te) = ES(e) – AT
  - SPI(te) = ES(e) / AT

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



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

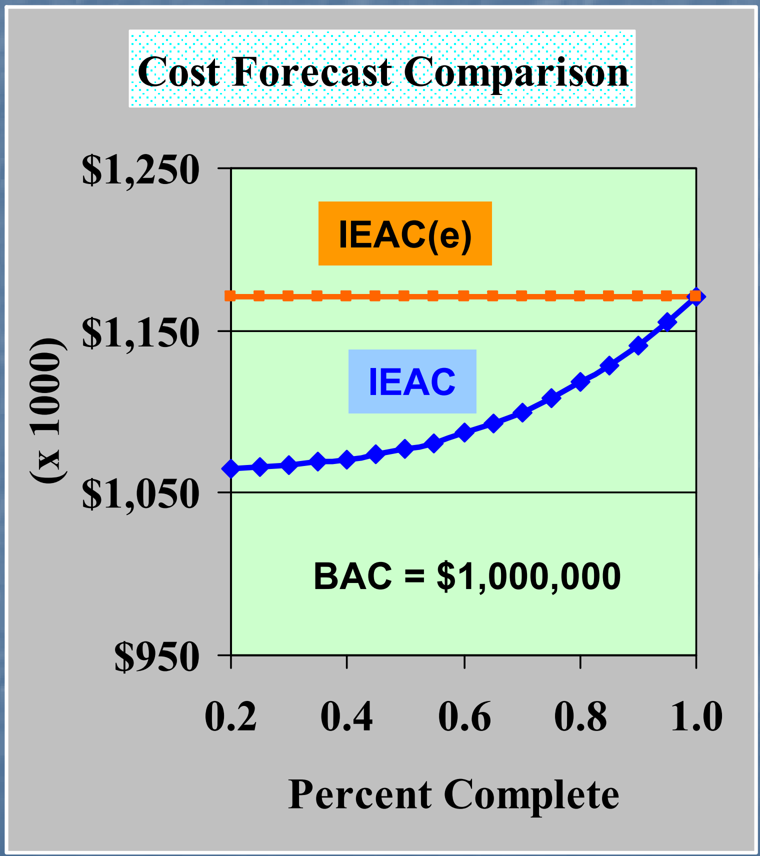


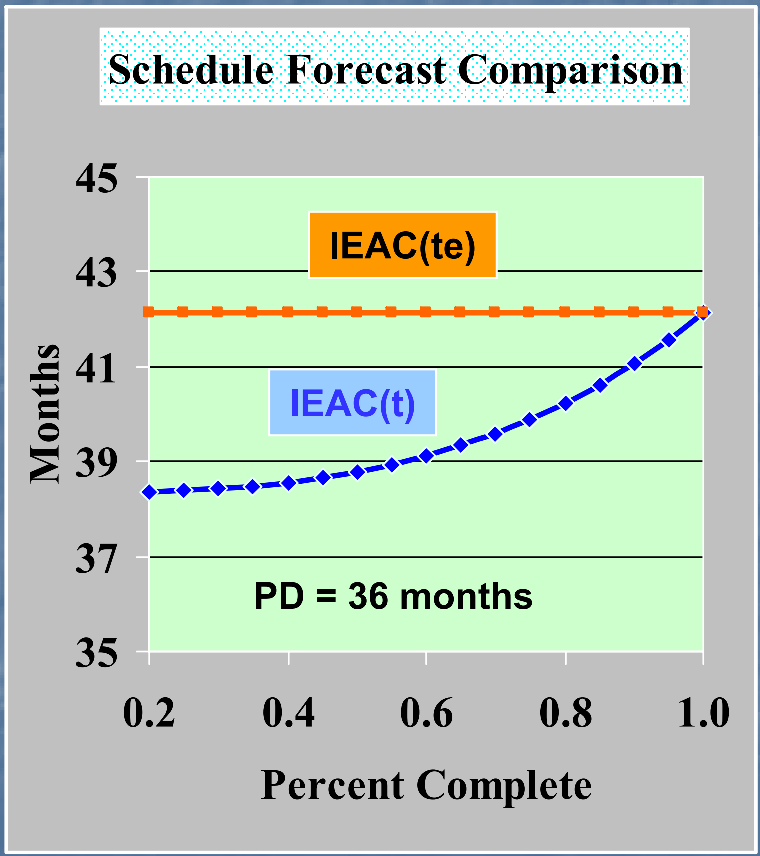
Forecasting with Effective Earned Value

Forecasting with Effective Earned Value

Schedule Prediction	IEAC(te) = PD / SPI(te)
Cost Prediction	IEAC(e) = BAC / CPI(e)

Schedule & Cost Prediction





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

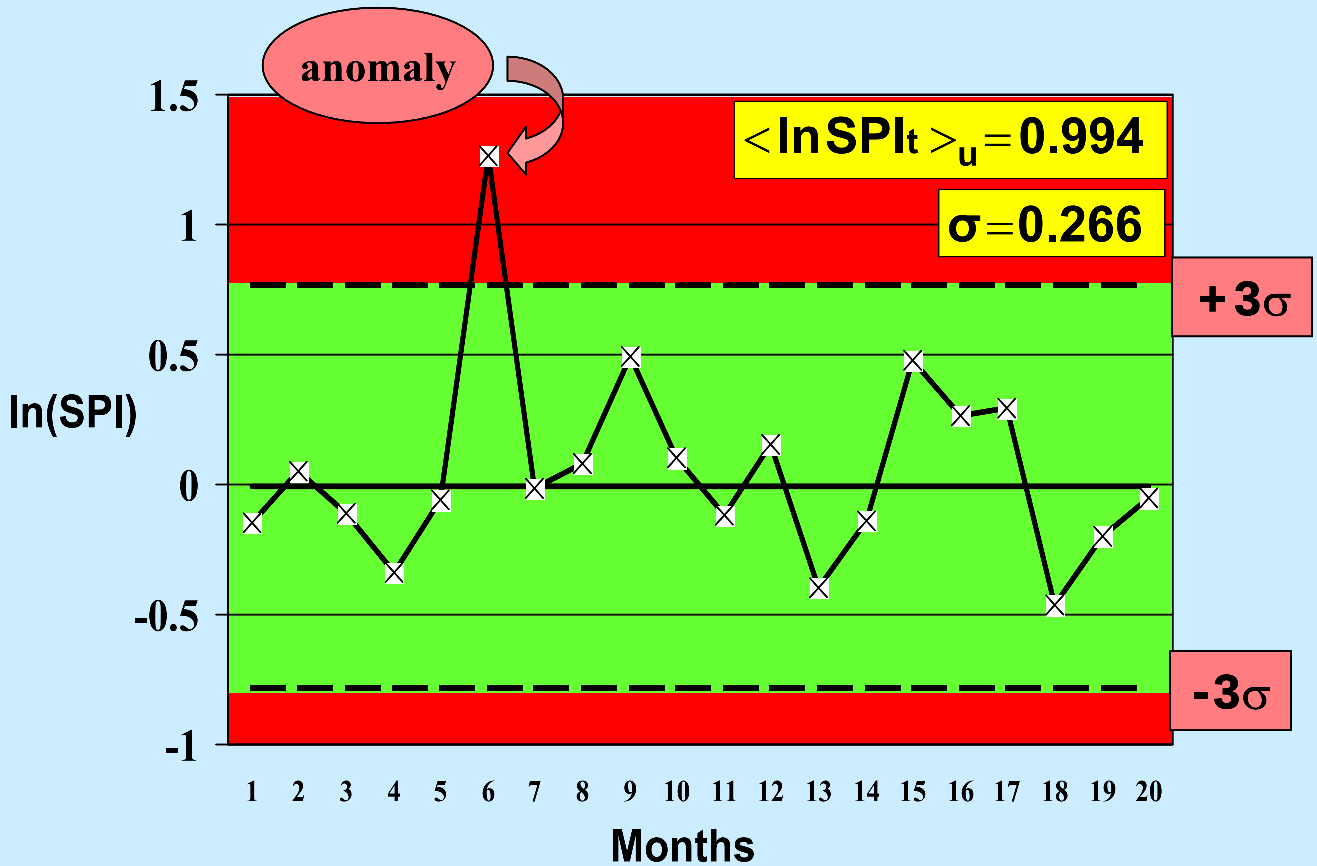
$$EV \Rightarrow BAC$$

  - 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

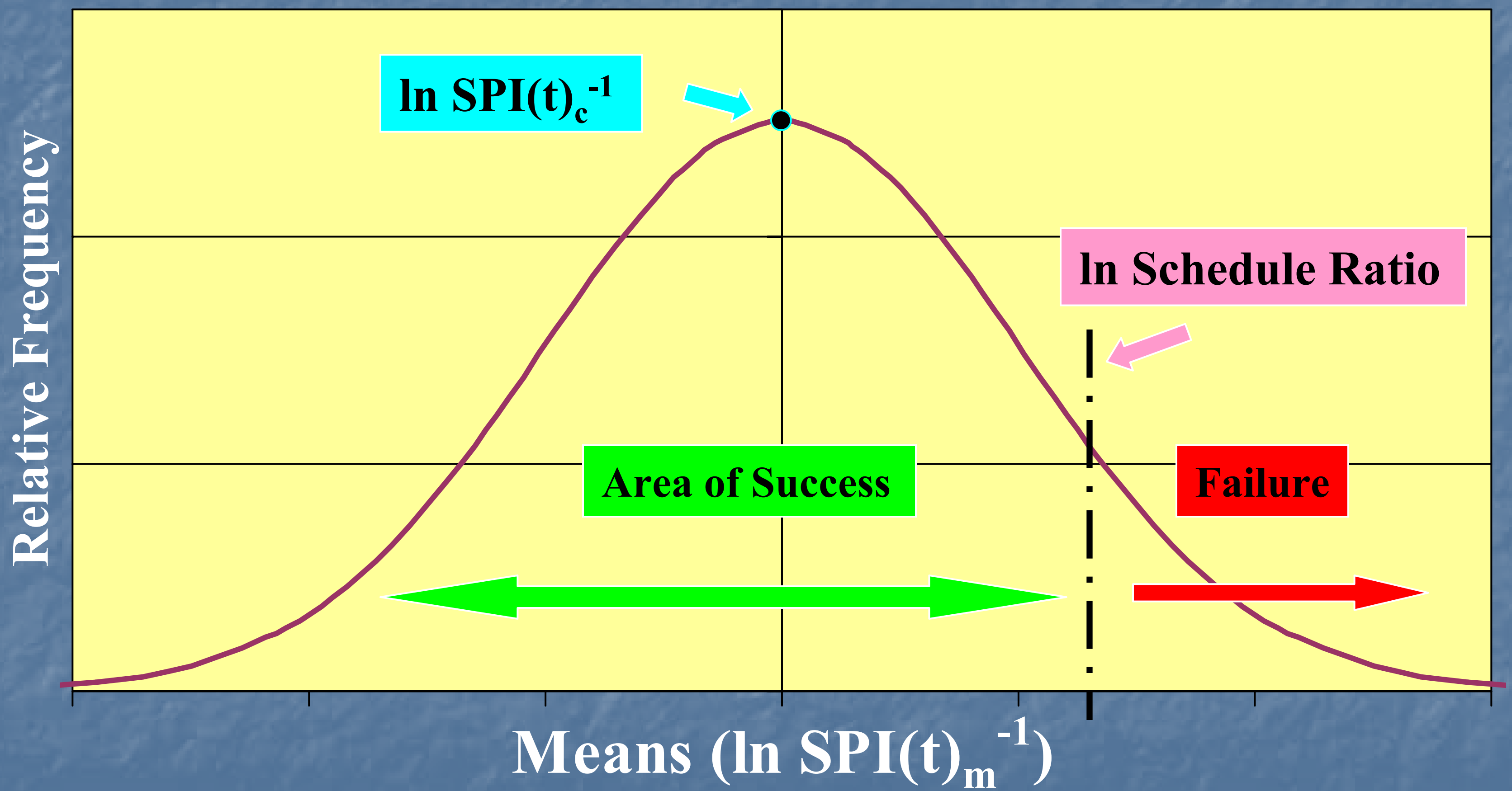
Statistical Process Control



Planning for Risk

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

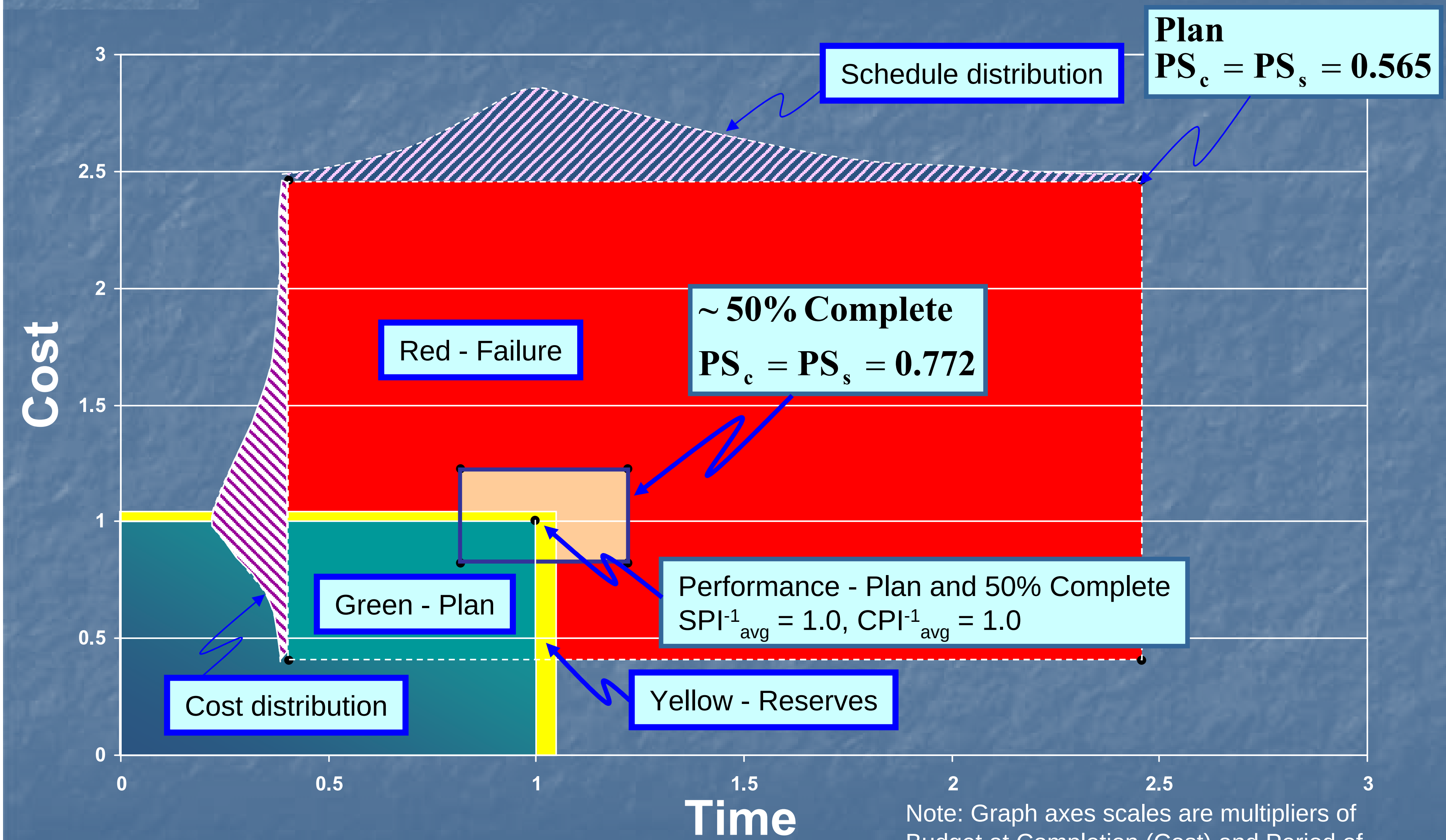
Planning for Risk



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).

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 (σ_*)

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 & today's impediments

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?

- o Time at which Actual Cost appears on PMB
- ☼ Time at which Planned Value equals Earned Value
- o Time at which Earned Value is reported
- o 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
- o Interpolated portion of the ES value
- o Earned Value accounting practice
- o 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?

- o How closely the project is following its plan
- o Why performance has the tendency to become less efficient as EV $\Rightarrow$ BAC
- o Improves analysis of true project accomplishment
- All of the above

Question #10

- How does Effective Earned Value differ from Earned Value?

- o Effective EV ≤ EV
- o Effective EV accounts for rework
- o Allows for earlier prediction of final project outcome
- ☼ All of the above
- o 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

the first scheduling system

www.earnedschedule.com

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