Earned Schedule
Workshop

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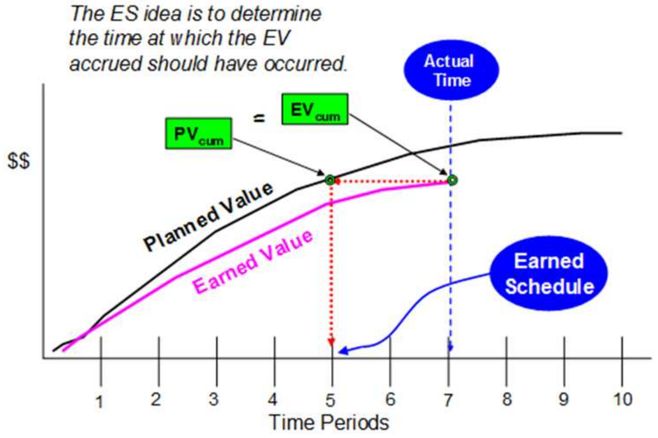


What Is Earned Schedule?

Earned Schedule is an extension to Earned Value Management. The method provides considerable capability to project managers for analysis of schedule performance. From the time of the public's first view of Earned Schedule, its propagation and uptake around the world has been extraordinary. This workshop will cover the theory, fundamentals, capabilities, affirmation, and resources available supporting the practice.

Objectives

- What is Earned Schedule?
- How does it relate to EVM?
- What can I do with ES?
- Are ES results reliable?
- Are other methods better?
- Does it take a lot of extra work?
- Will ES help me manage?

Earned Schedule - Overview

- EVM Schedule Indicators
- Concept & Metrics
- Computation Example
- Indicators
- Prediction, Forecasting
- Terminology
- Verification of Concept

Earned Schedule - Overview

- EVM (time) – ES Comparison
- *Exercise – Calculate ES, SV(t), SPI(t)*
- *Demonstrate – ES Calculator*
- *Demonstrate – Forecasting*
- *Demonstrate – Prediction*
- ES Usage & Propagation
- Summary Basic

Earned Schedule - Overview

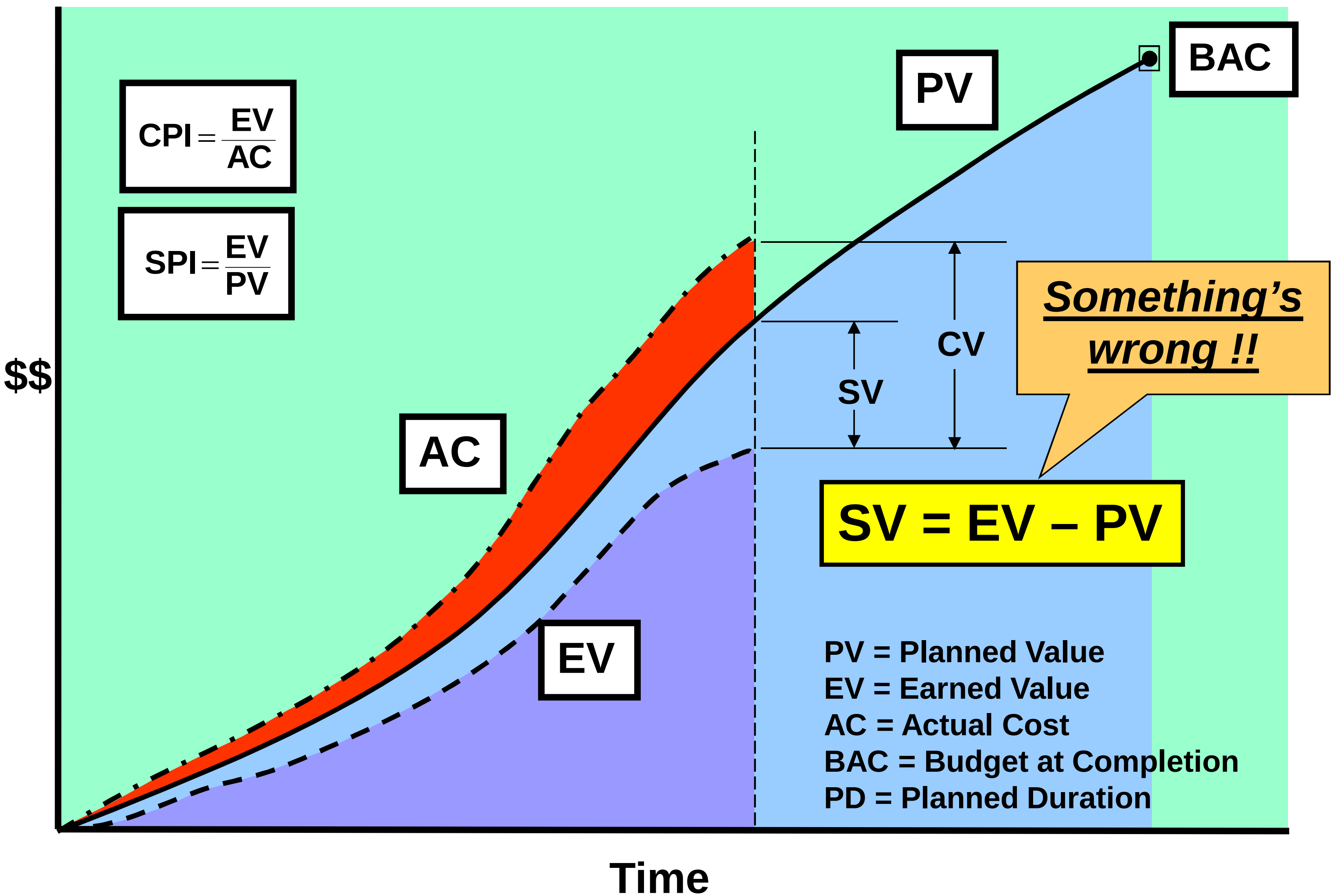
- Advanced Methods
- Critical Path Application
- *Demonstrate – Critical Path Analysis*
- Schedule Adherence
- SA Index & Rework Forecast
- Statistical Methods
- Small Projects
- Longest Path Forecasting

Earned Schedule - Overview

- Advanced Methods Summary
- Application Help
- Review Questions
- Wrap Up

Introduction to Earned Schedule

EVM Schedule Indicators



EVM Schedule Indicators

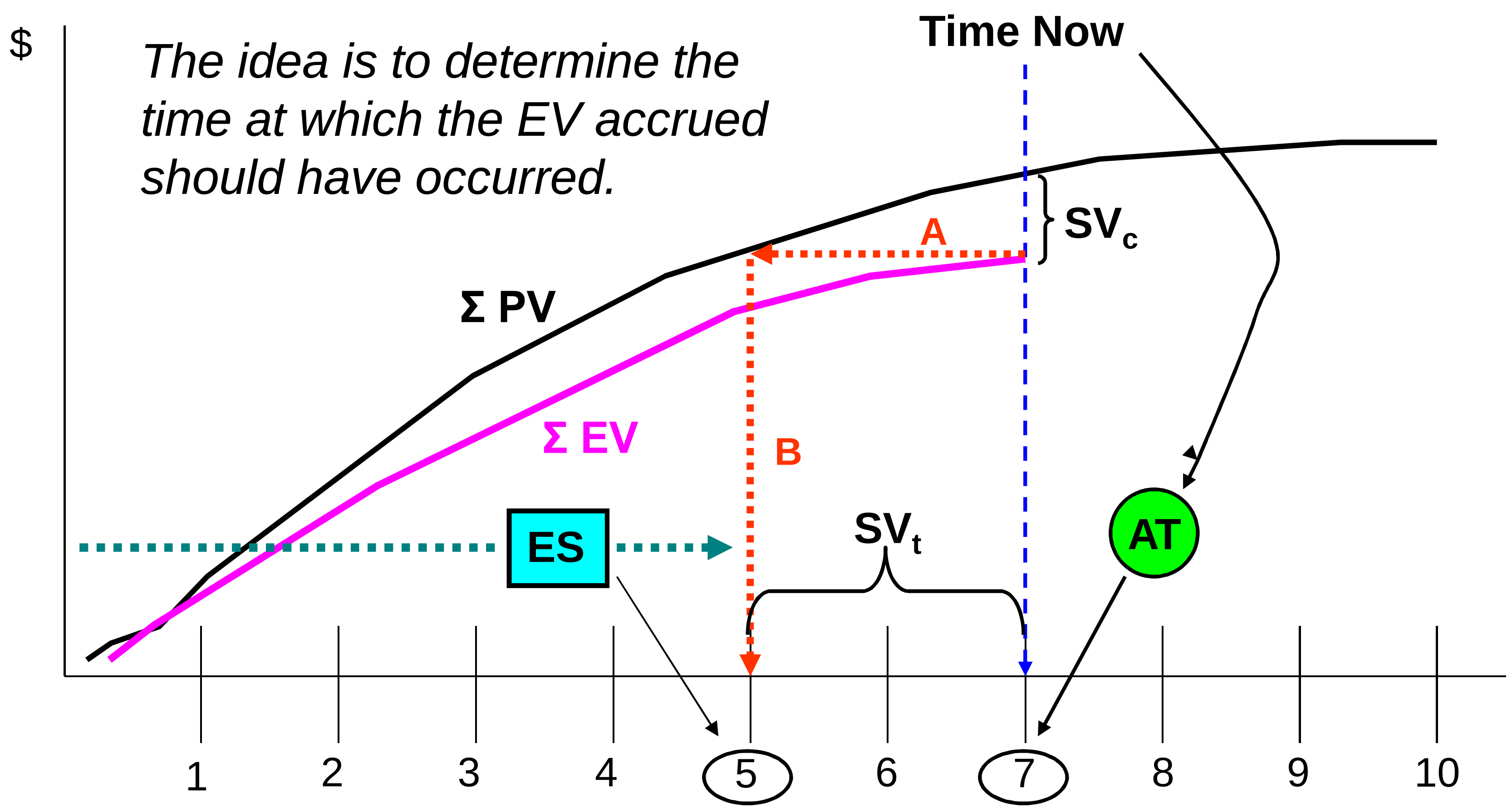
- SV & SPI behave erratically for projects behind schedule
  - SPI improves and concludes at 1.00 at end of project
  - SV improves and concludes at $0 variance at end of project
- Schedule indicators lose predictive ability over the last third of the project

EVM Schedule Indicators

- Why does this happen?
  - SV = EV – PV
  - SPI = EV / PV
- At planned completion PV = BAC
- At actual completion EV = BAC
- When actual > planned completion
  - SV = BAC – BAC = $000
  - SPI = BAC / BAC = 1.00

Regardless of lateness !!

Earned Schedule Concept



For the above example, ES = 5 months …that is the time associated with the PMB at which PV equals the EV accrued at month 7.

Earned Schedule Metric

- Required measures
  - Performance Measurement Baseline (PMB) – the time phased planned values (PV) from project start to completion
  - Earned Value (EV) – 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 Calculation

- ES (cumulative) is the:

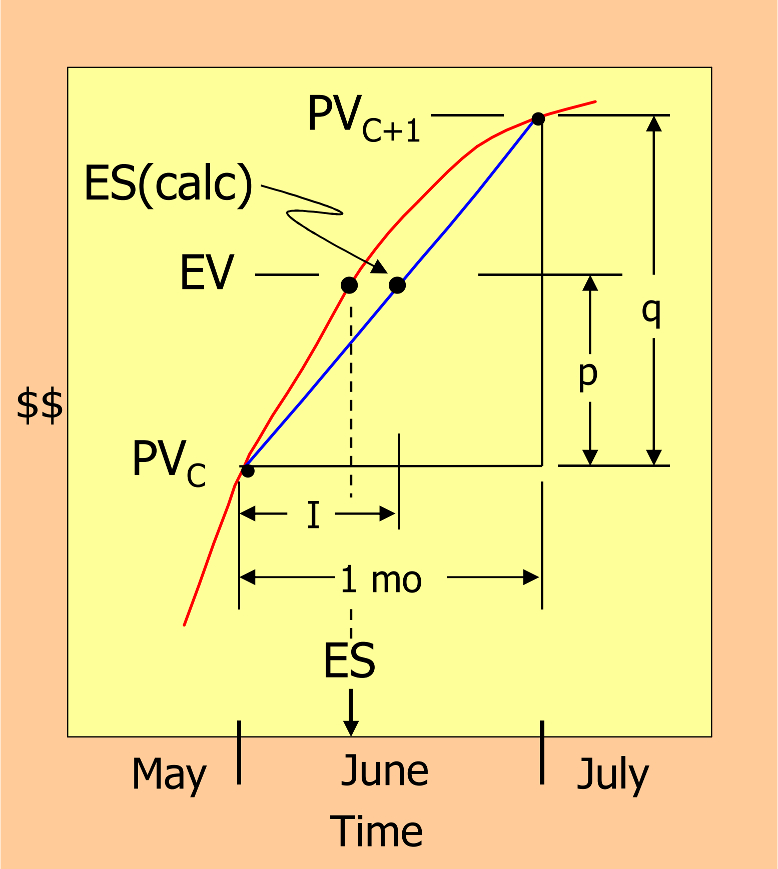
  Number of time increments (C) of PMB for which EV accrued equals or exceeds PV_n, plus the fraction (I) of the subsequent increment (C + 1)

- ES = C + I where:

  C = Number of time increments of PMB for EV $\geq PV_n$

  $I = (EV - PV_C) / (PV_{C+1} - PV_C) * \text{one time period}$

Interpolation Calculation



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

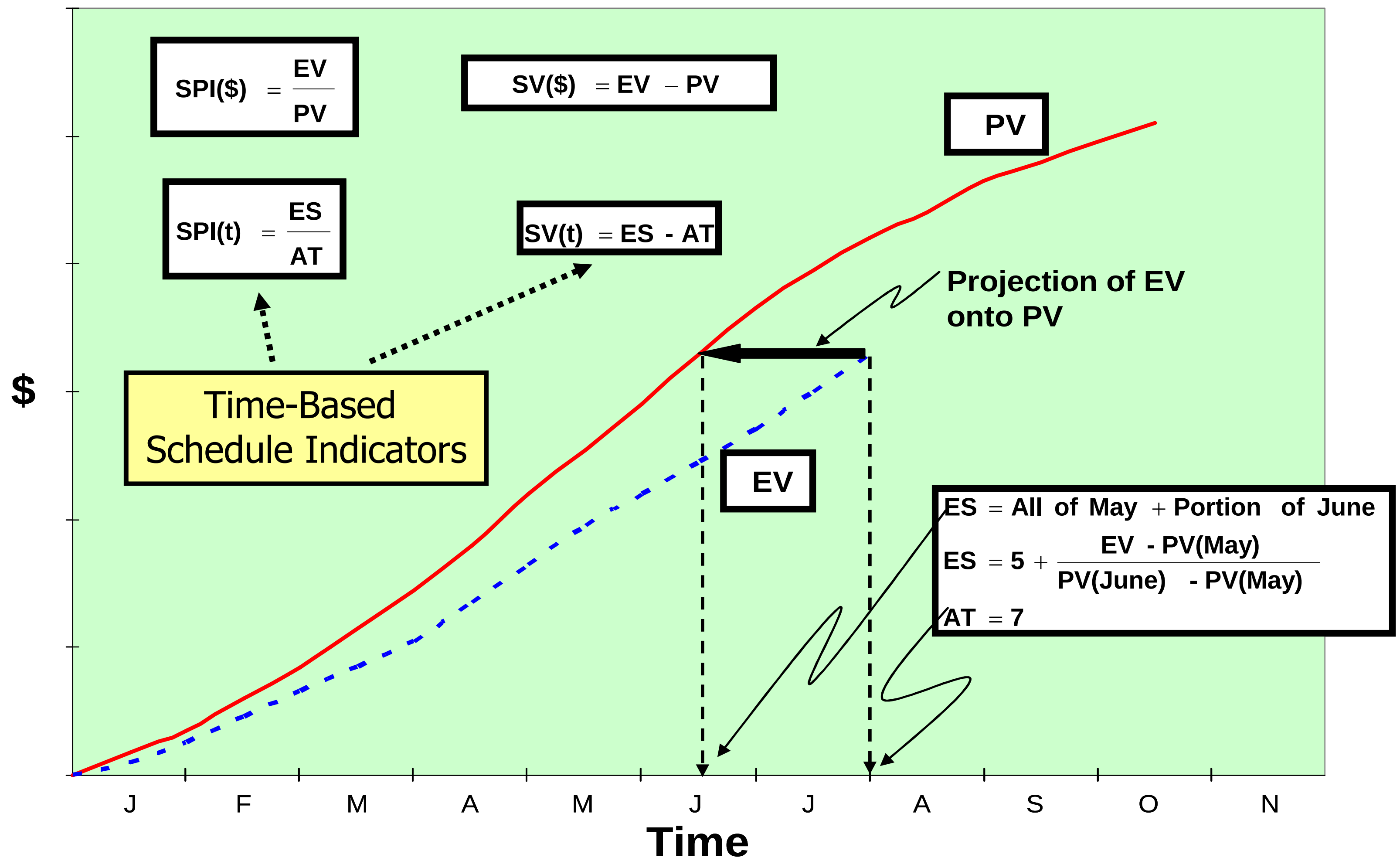
$I = (p / q) * 1 \text{ mo}$

$p = EV - PV_C$

$q = PV_{C+1} - PV_C$

$$I = \frac{EV - PV_C}{PV_{C+1} - PV_C} * 1\text{mo}$$

ES Computation Example

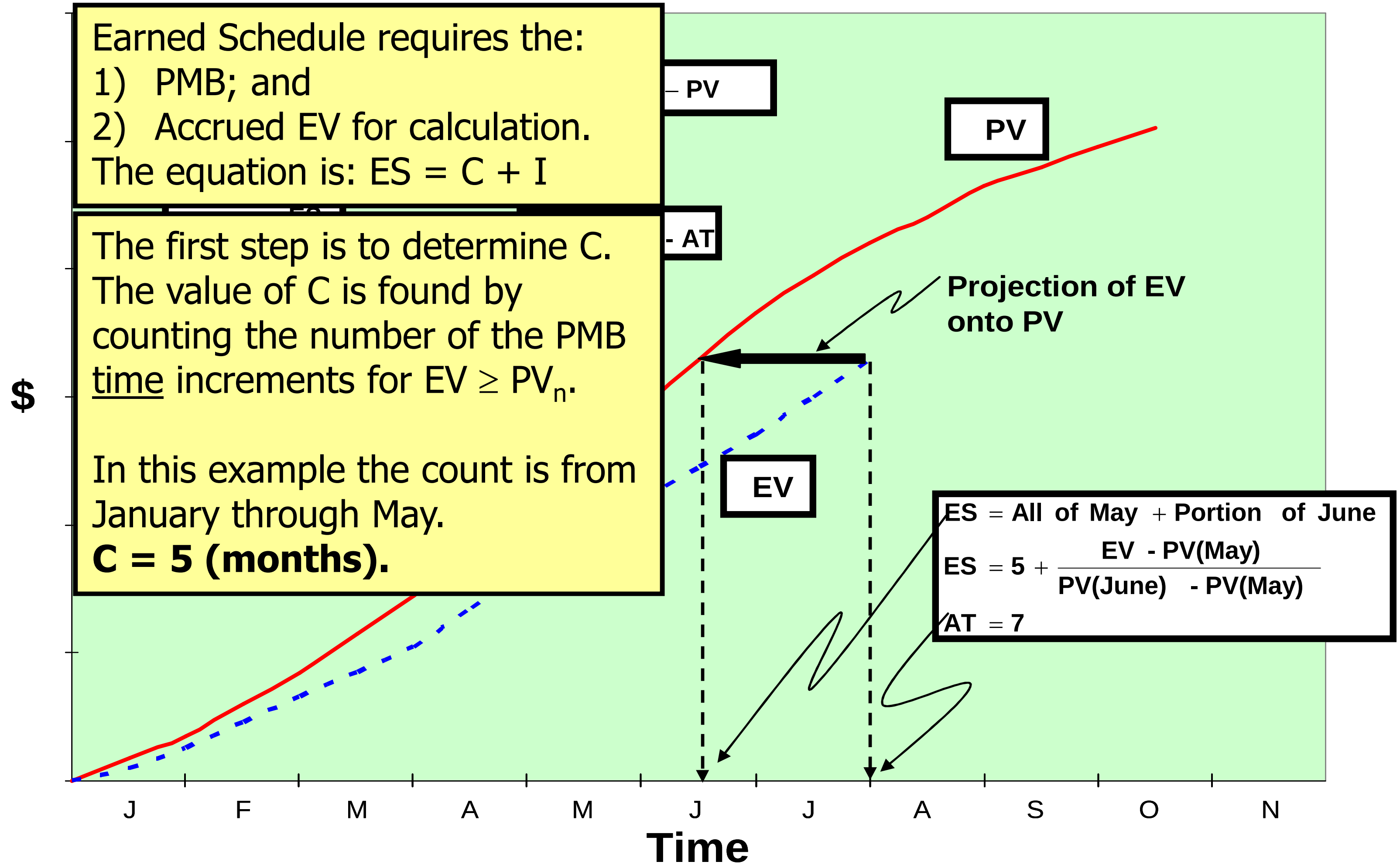


ES Computation Example

Earned Schedule requires the:
1) PMB; and
2) Accrued EV for calculation.
The equation is: ES = C + I

The first step is to determine C. The value of C is found by counting the number of the PMB <u>time</u> increments for EV ≥ PV_n.

In this example the count is from January through May.
C = 5 (months).



ES Computation Example

Thus far, ES = 5 + I (months).
In the small box at the lower right, is the equation for calculating I.
For the example, let
1) EV = 100
2) PV_5 (May) = 90
3) PV_6 (June) = 110.

Let's calculate I:
I = (100 – 90) / (110 – 90) = 0.5

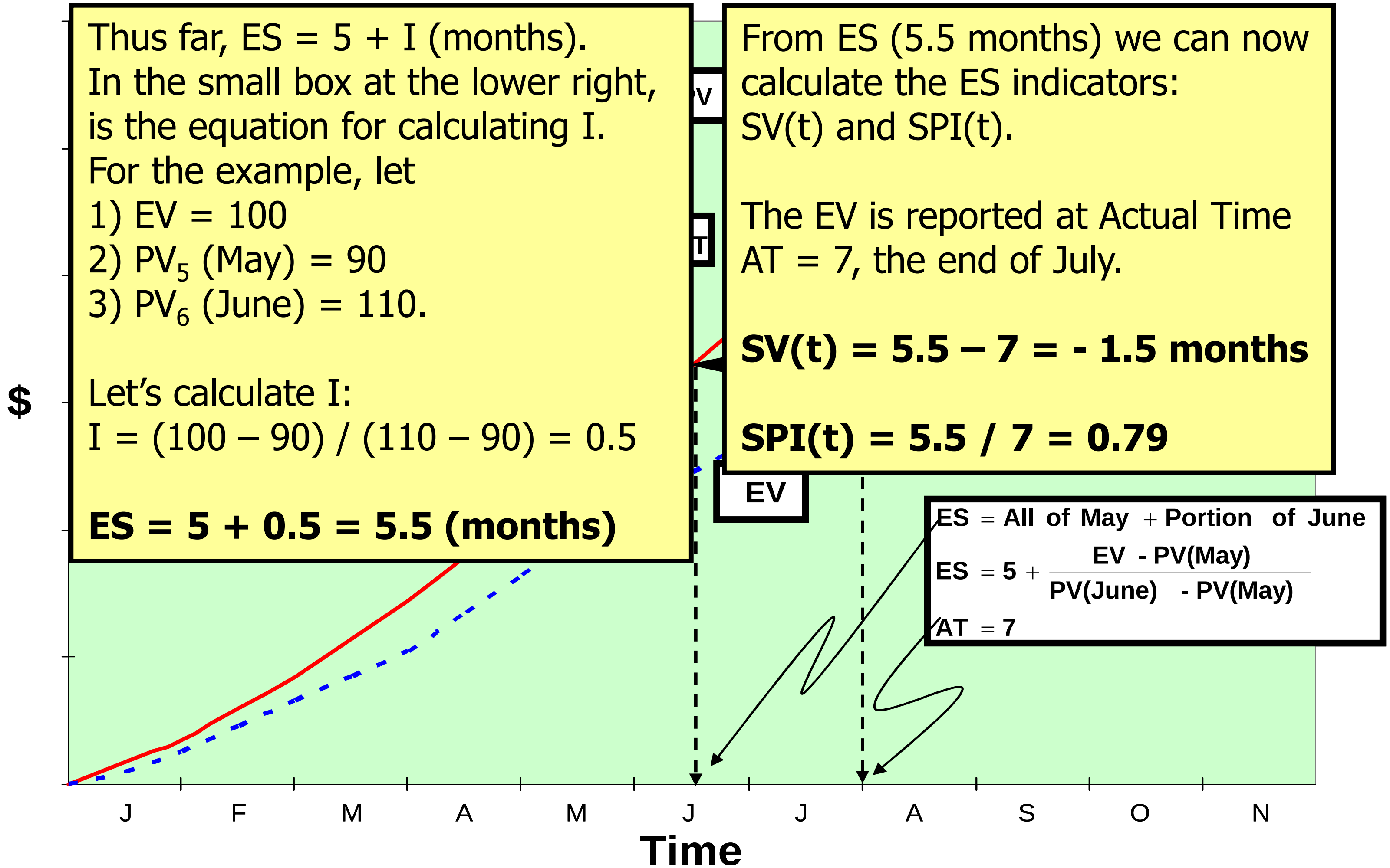
ES = 5 + 0.5 = 5.5 (months)

From ES (5.5 months) we can now calculate the ES indicators:
SV(t) and SPI(t).

The EV is reported at Actual Time AT = 7, the end of July.

SV(t) = 5.5 – 7 = - 1.5 months

SPI(t) = 5.5 / 7 = 0.79



ES Periodic Metrics

- Periodic measures are needed for trending
- Periodic measures are derived from the cumulative measures
- $ES_{period}(n) = ES_{cum}(n) – ES_{cum}(n\text{-}1) = \Delta ES_{cum}$
- $AT_{period}(n) = AT_{cum}(n) – AT_{cum}(n\text{-}1) = \Delta AT_{cum}$
  - 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

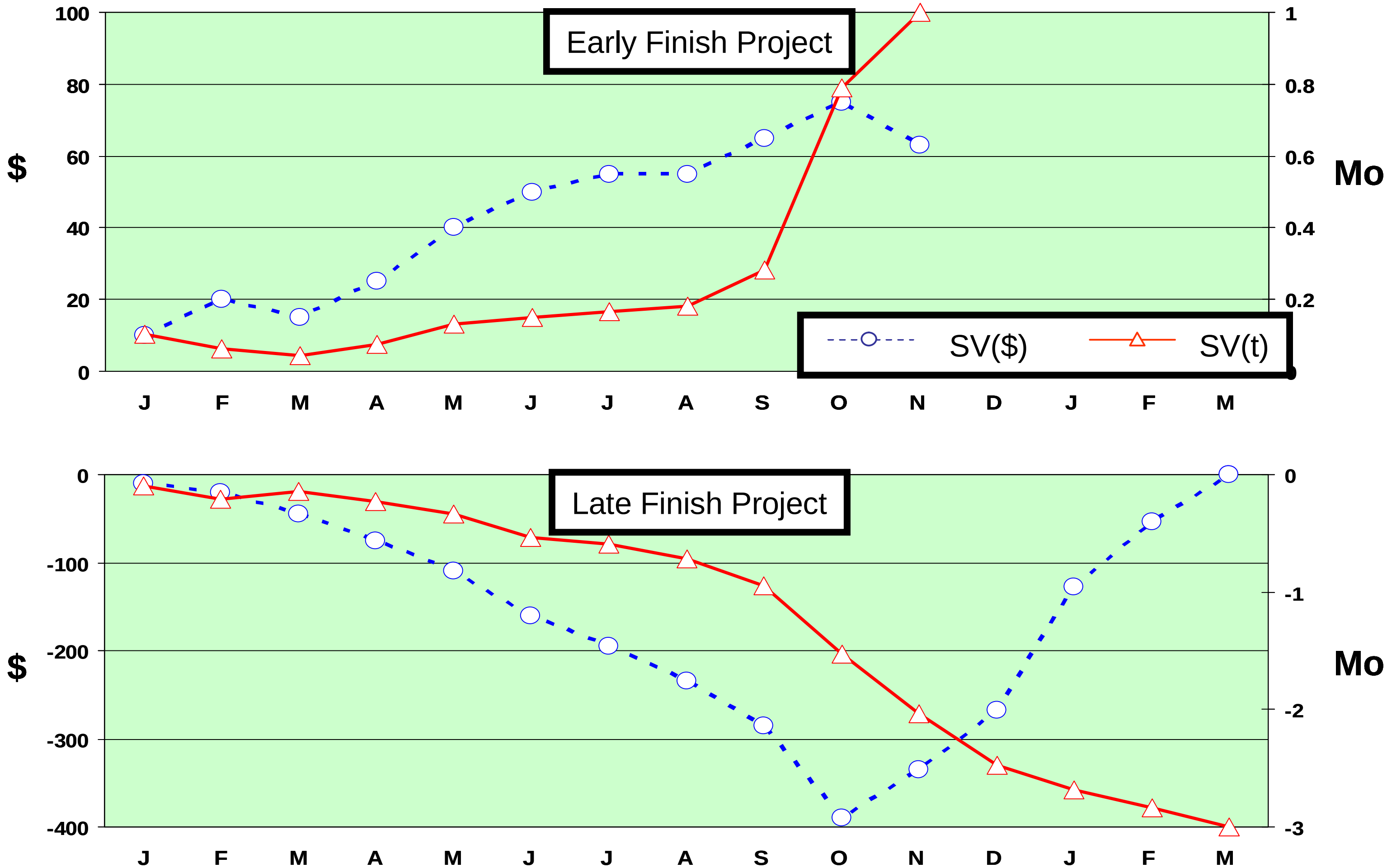
- What happens to the ES indicators, SV(t) & SPI(t), when the planned project duration (PD) is exceeded (PV = BAC)?

    They Still Work …Correctly!!

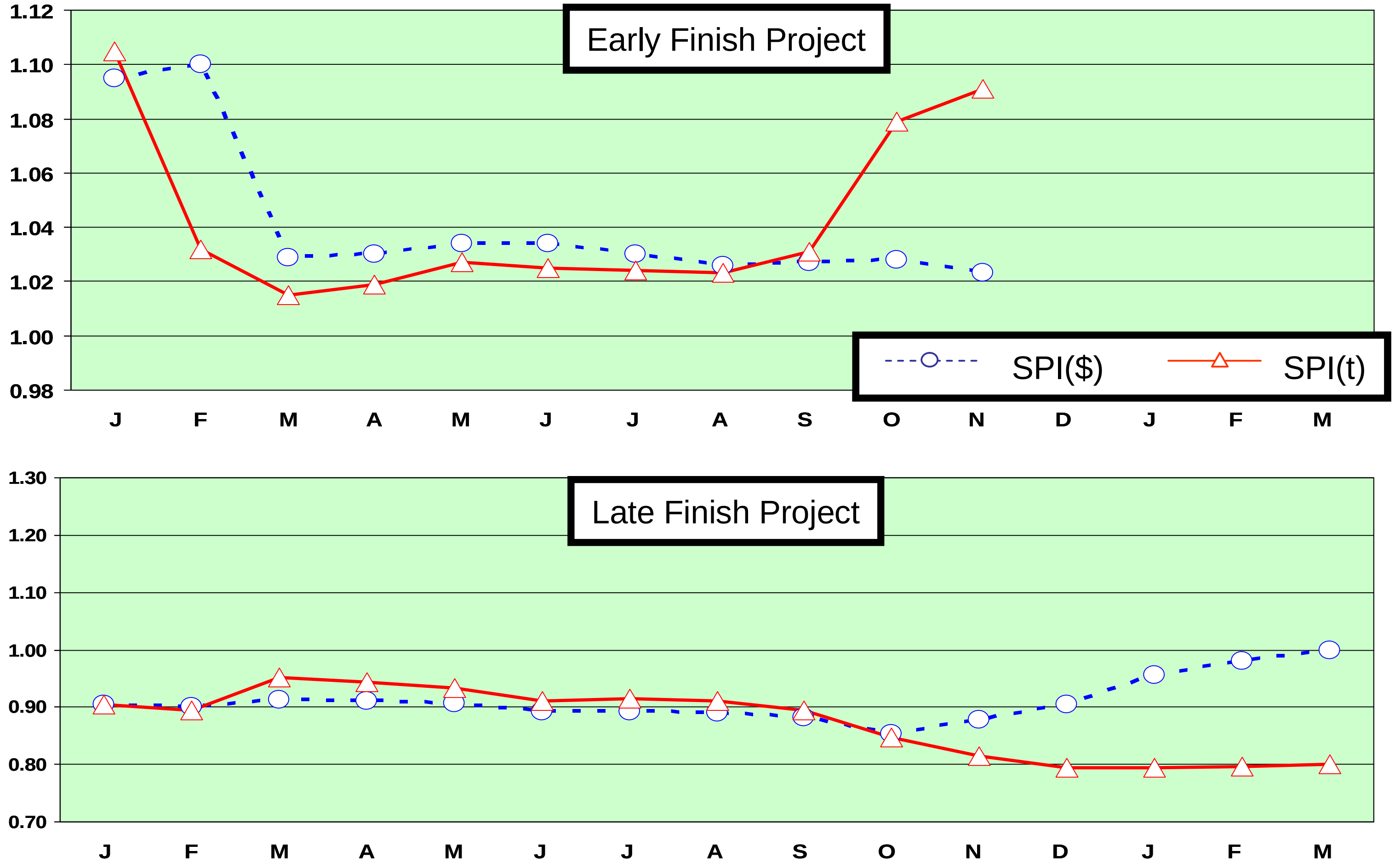
- ES will be ≤ PD, while AT > PD
    - SV(t) will be negative (time behind schedule)
    - SPI(t) will be < 1.00

    Reliable Values from Start to Finish !!

SV Comparison



SPI Comparison



Earned Schedule Key Points

- ES schedule indicators behave in an analogous manner to the EVM cost indicators, CV and CPI
- SV(t) and SPI(t)
  - Not constrained by BAC calculation reference
  - Provide duration based indicators of schedule performance
  - Valid for entire project, including early and late finish
- Facilitates integrated Cost/Schedule Management *(using EVM with ES)*

Prediction, Forecasting and Terminology

Earned Schedule Prediction

- To Complete Schedule Performance Index (TSPI)
- 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
- …..completed as estimated?
  - TSPI = (PD – ES) / (ED – AT)

    where ED = Estimated Duration

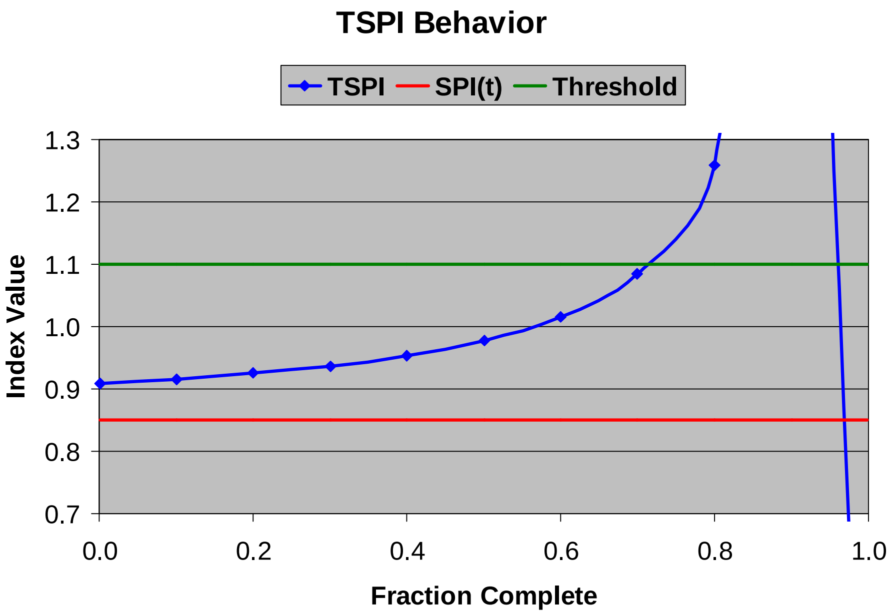
Earned Schedule Prediction

- Threshold value of 1.10 has been used historically, but has not been well studied or verified
- Recent analysis indicates TSPI values provide reliable and useful management information

TSPI Value	Predicted Outcome
≤ 1.00	Achievable
1.00 - 1.10	Recoverable
> 1.10	Not Achievable

Earned Schedule Prediction

- Why does TSPI > 1.10 indicate the project cannot recover?
  - At 1.10, for modest increases in EV, the rate of change of TSPI becomes increasingly larger
  - Once the threshold is exceeded, there is little hope that management intervention can have positive impact …the project is very rapidly becoming “out of control”



Earned Schedule Forecasting

- Long time goal of EVM …*Forecasting 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 forecast final cost
- Independent Estimated Completion Date (IECD)
  - IECD = Start Date + IEAC(t)

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)

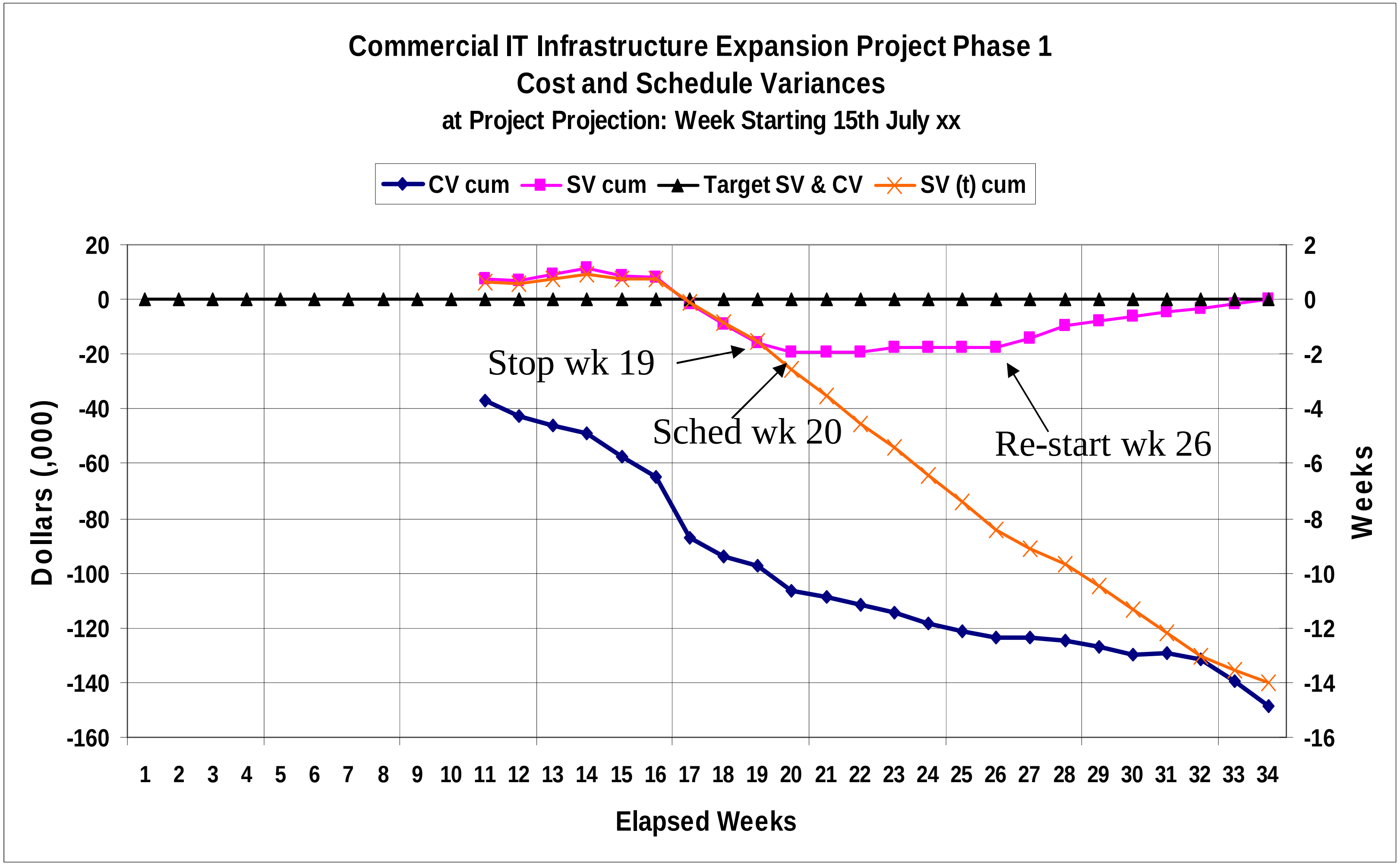
Earned Schedule Terminology

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
		SV(t)%	SV(t)% = (ES – AT) / ES
	Schedule Performance Index	SPI(t)	SPI(t) = ES / AT
	To Complete Schedule Performance Index	TSPI	TSPI = (PD – ES) / (PD – AT)
			TSPI = (PD – ES) / (ED – AT)
Predictors	Independent Estimate at Completion (time)	IEAC(t)	IEAC(t) = PD / SPI(t)
			IEAC(t) = AT + (PD – ES) / PF(t)
	Variance at Completion	VAC(t)	VAC(t) = PD - IEAC(t) or ED

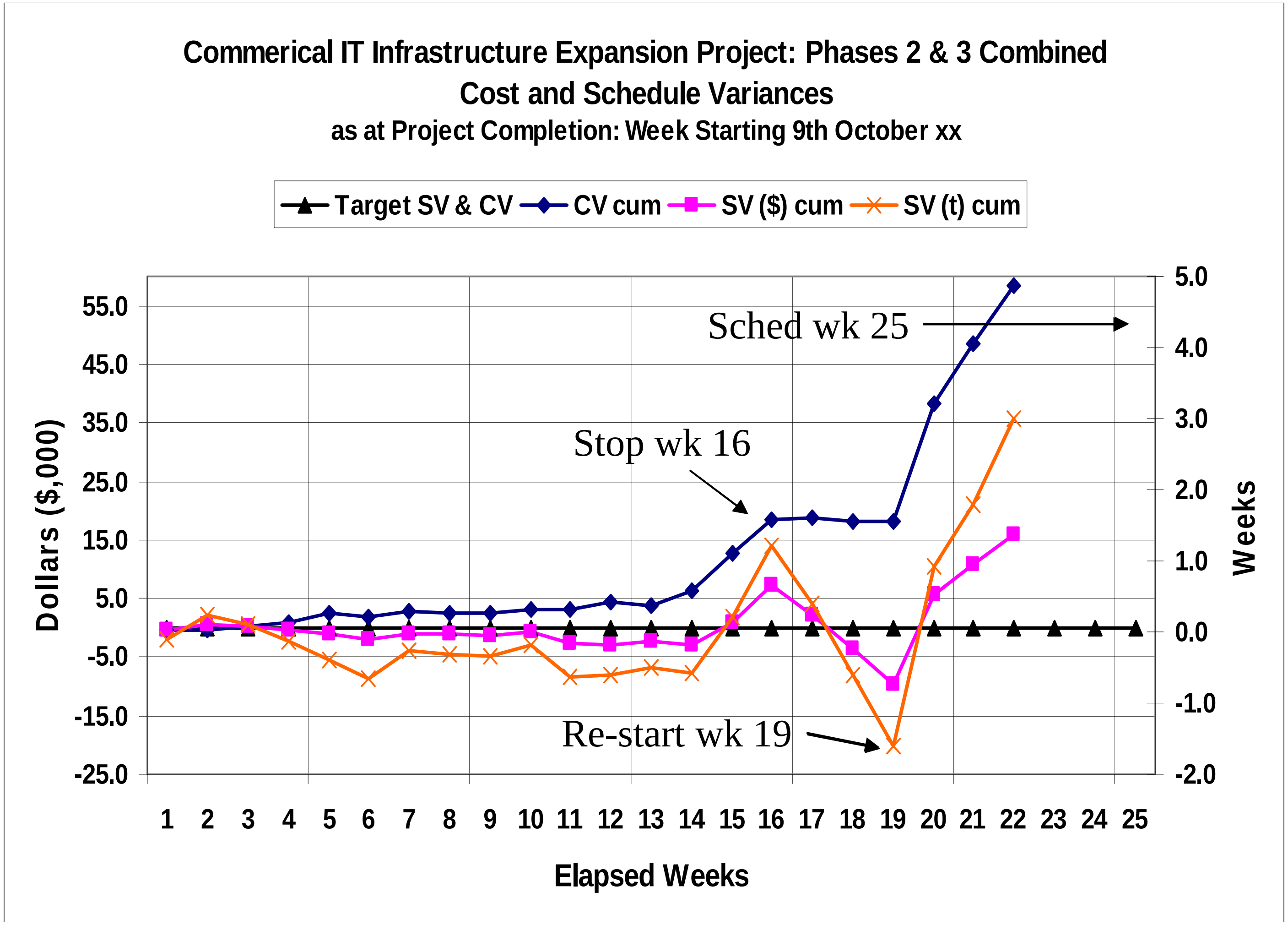
Verification of Concept

ES Applied to Real Project Data:

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



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



IEAC(t) Forecast Comparison

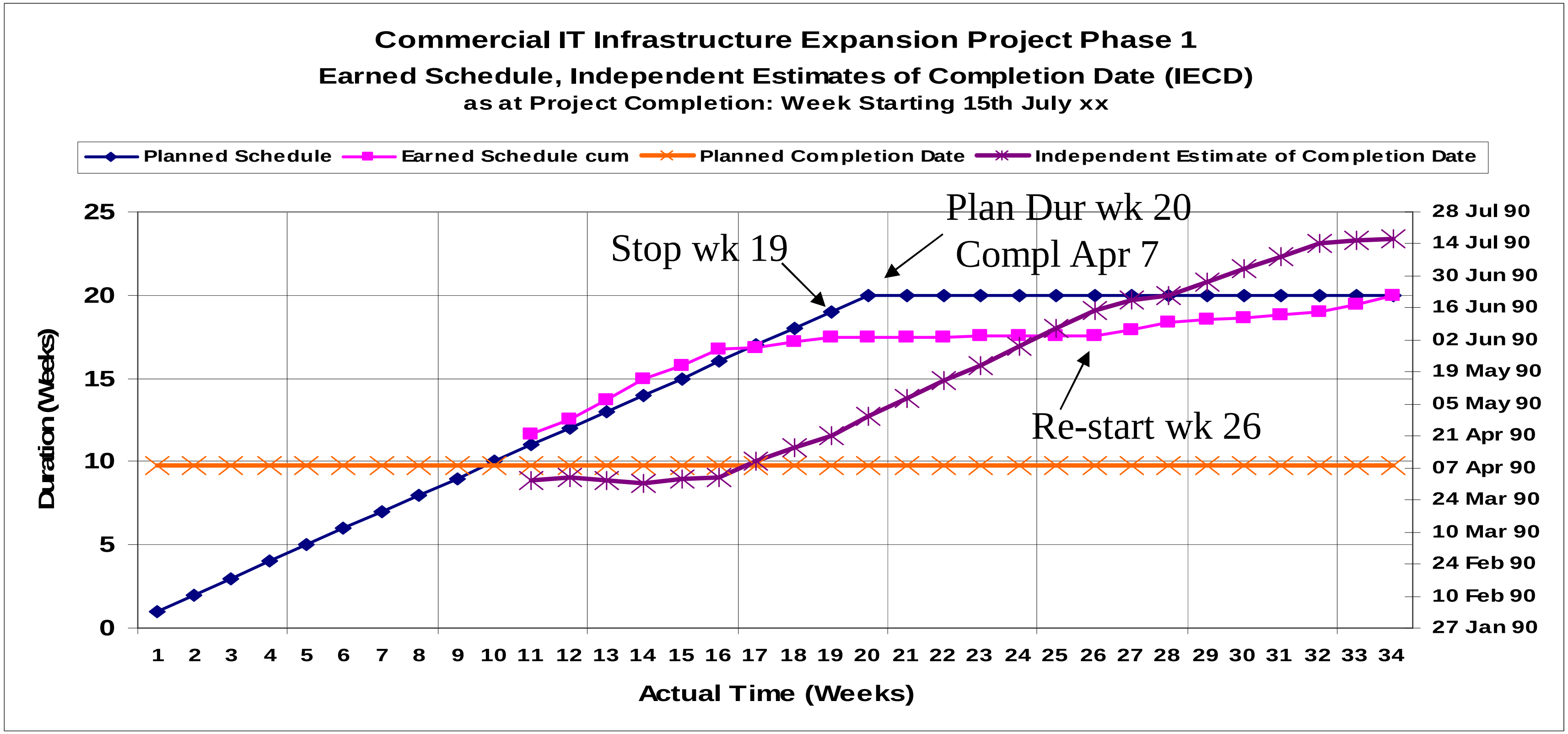
Early and Late Finish Project Examples

Project Data	Early Finish - weeks -	Late Finish - weeks -
Planned Duration	25	20
Actual Duration	22	34
CPI	2.08	0.52
SPI	1.17	1.00
SPI(t)	1.14	0.59
IEAC(t) Forecasts		
PD / SPI(t)	22.0	34.0
PD / SPI	21.4	20.0
PD / (CPI * SPI)	10.3	38.5

- In both examples, the **pre ES** forecasts (in red & orange) **fail** to correctly calculate the Actual Duration at Completion!
- The ES forecast alone **correctly** calculates the Actual Duration at Completion in both cases

IECD Forecasts using ES Techniques

Independent Estimate of Completion Date



Independent Confirmation

- SPI(t) & SV(t) do portray the real schedule performance
- At early & middle project stages pre-ES & ES forecasts of project duration produce similar results
- At late project stage ES forecasts outperform all pre-ES forecasts

Independent Confirmation

- "The results reveal that the earned schedule method outperforms, on the average, all other forecasting methods."

Mario Vanhoucke & Stephan Vandevoorde
"A Simulation and Evaluation of Earned Value Metrics to Forecast Project Duration"
Journal of the Operational Research Society (2007, Issue 10)

- "This research finds Earned Schedule to be a more timely and accurate predictor than Earned Value Management."

Kevin Crumrine & Jonathan Ritschel
"A Comparison of Earned Value Management and Earned Schedule as Schedule Predictors on DOD ACAT 1 Programs"
The Measurable News (2013, Issue 2)

EVM (time) versus ES

Real Data

Schedule Variance (time)

Duration Forecasting

EVM - SV Time Calculation Methods

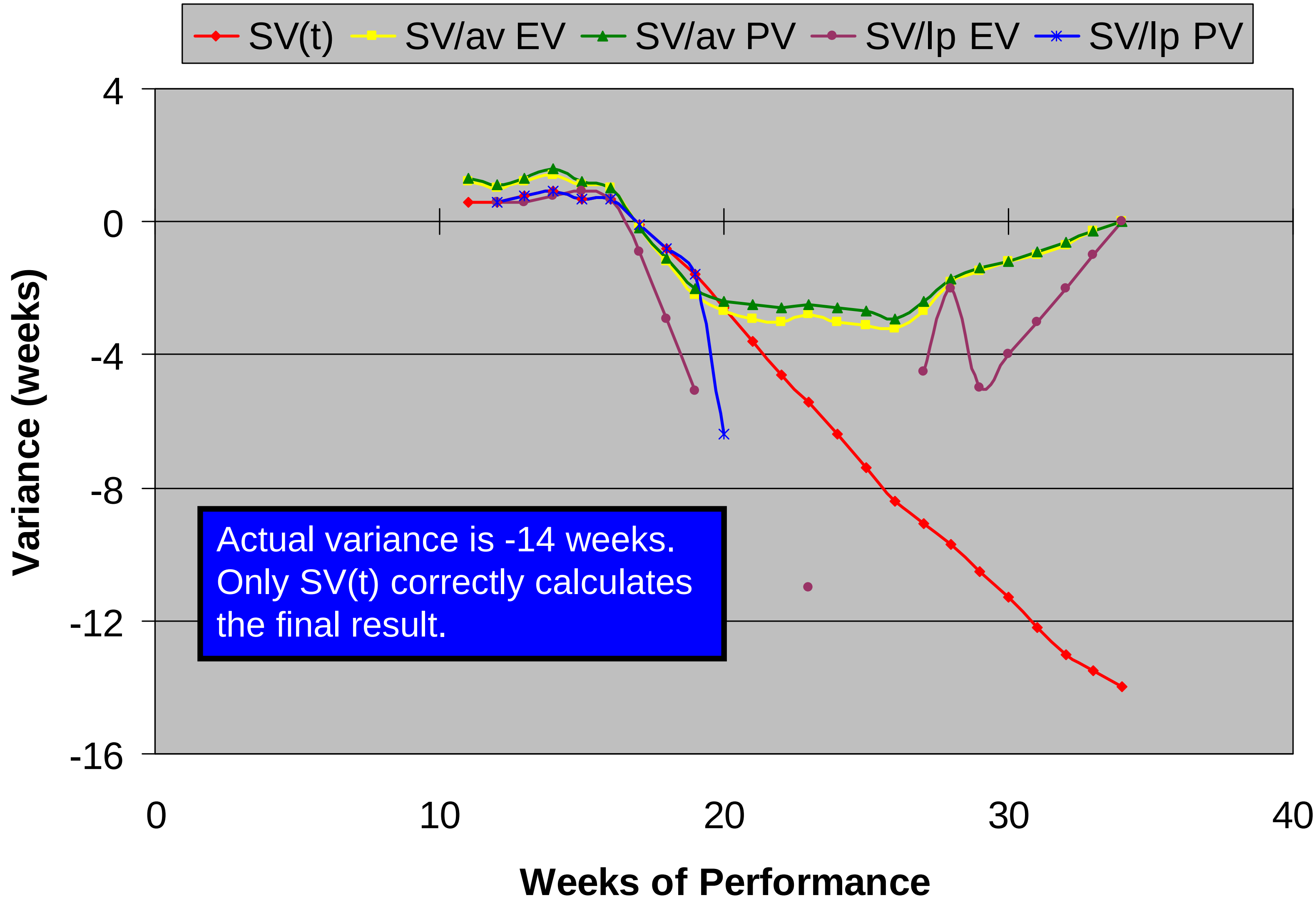
- Four EVM-based calculation methods in use
  - $SV_{avPV} = SV(\$) / (PV_{cum} / n)$
  - $SV_{avEV} = SV(\$) / (EV_{cum} / n)$

    where n = number of time periods (months, weeks)
  - $SV_{lpPV} = SV(\$) / PV_{lp}$
  - $SV_{lpEV} = SV(\$) / EV_{lp}$

    where lp = last period
- Apply EVM methods to Late Finish project data

How well do they work?

Comparison of SV Time Methods



EVM - SV Time Methods Conclusions

- Last period methods have more volatility and a greater likelihood of providing erroneous information
- Averaging methods provide good results for the early portion but fail for late finish projects by concluding at zero variance
- SV(t) from ES provides reliable results throughout the period of performance

EVM Time Forecasting Methods

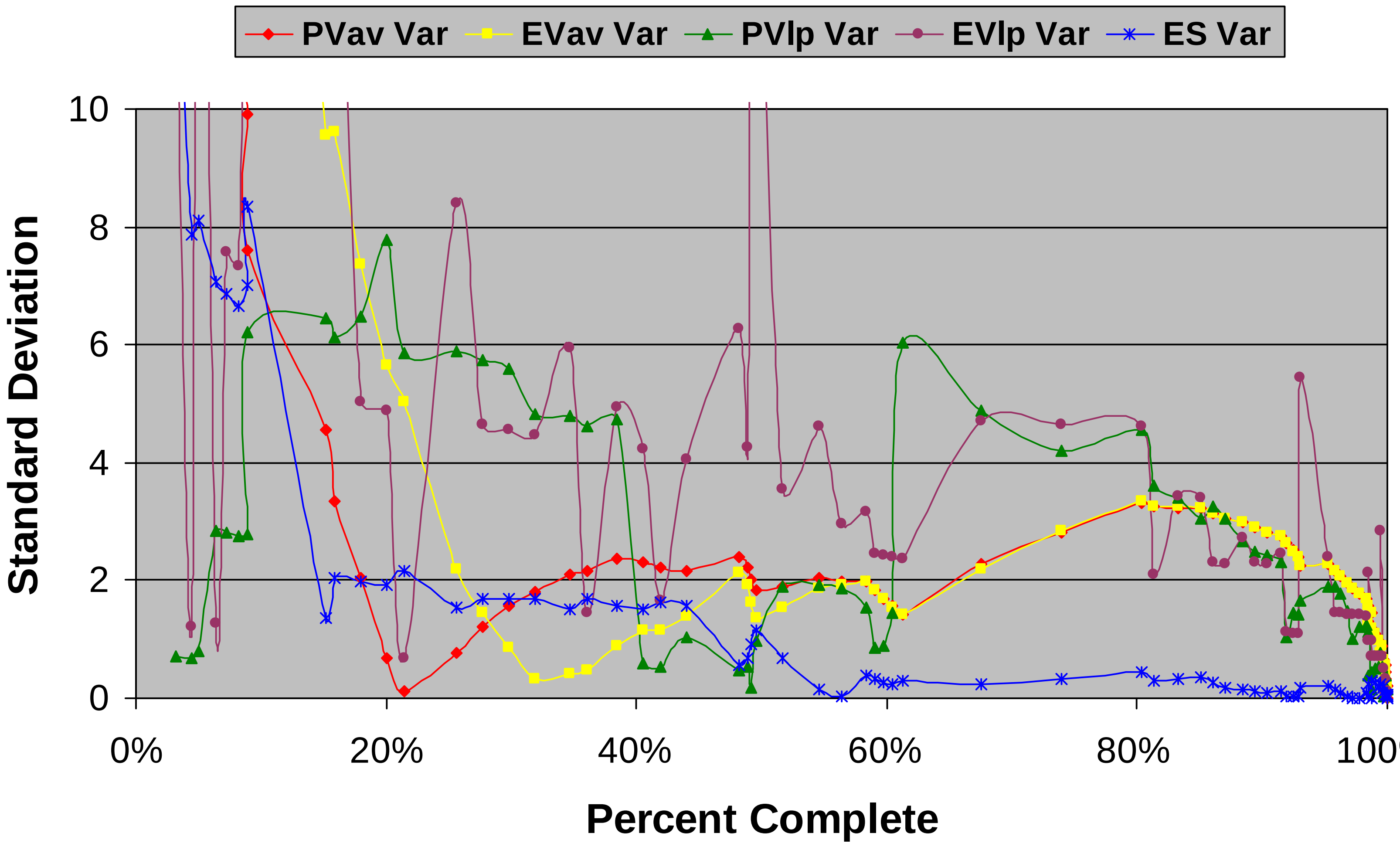
- Four Methods – all having same basic construct
  - Forecast Time = Current Duration + Time to Complete
  - Time to Complete = Work Remaining / (Work Rate)
- Fundamental equation
  - IEAC(t) = AT + (BAC – EV) / Work Rate
- Work Rates (Cost or Labor Hours per Unit of Time)
  - PV average = PV_{cum} / number of observations (n)
  - EV average = EV_{cum} / number of observations (n)
  - PV last period
  - EV last period

EVM & ES Forecasting

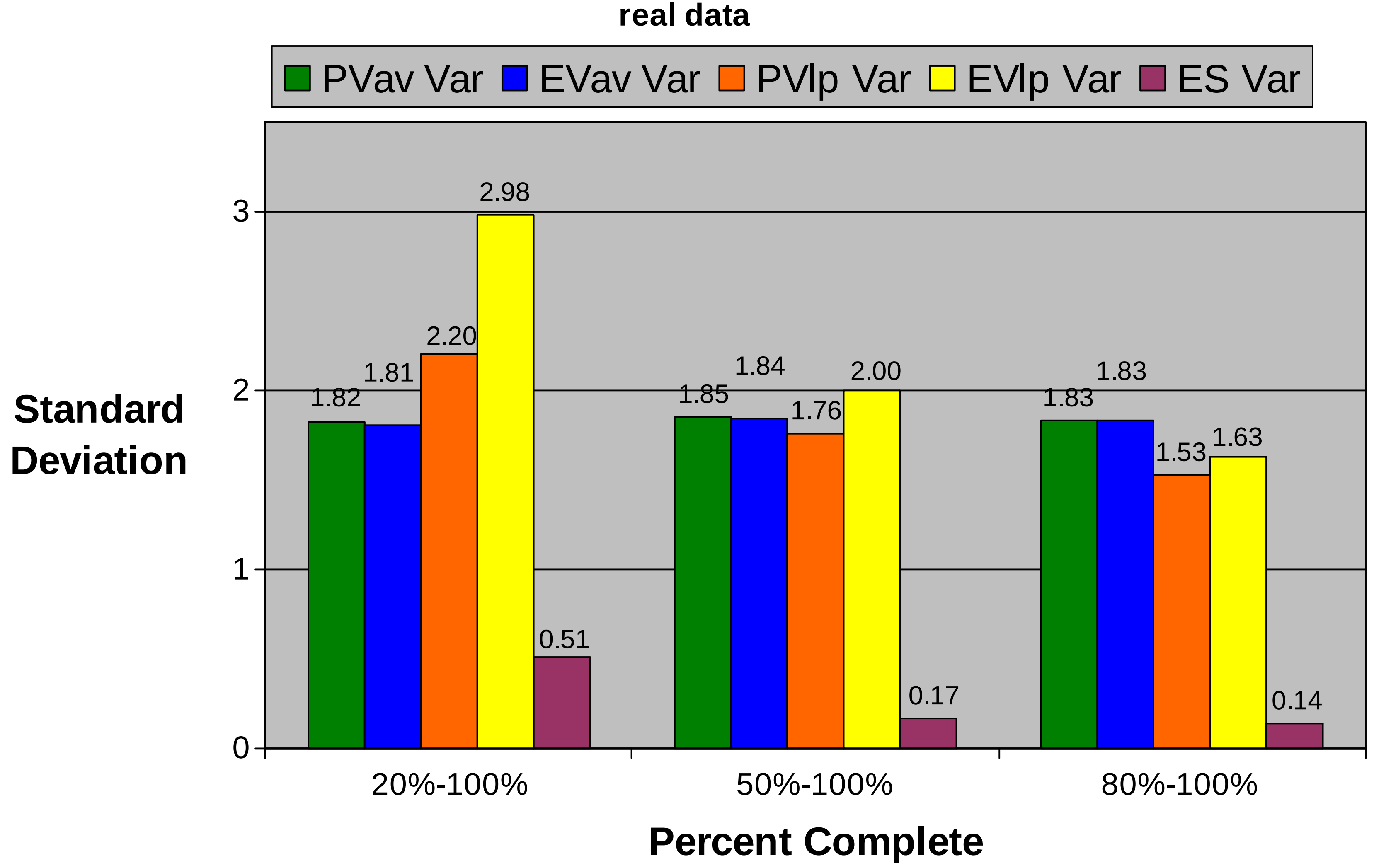
- Forecasting with ES uses the following equation
  - IEAC(t) = Planned Duration / SPI(t)
- The four EVM Methods are applied to **real project data** and compared to the ES prediction in four graphical charts following.
- As you will see, the last period work rates provide erratic results. The average work rates are less volatile, but are not necessarily better.

Time Forecasting Std Dev Comparisons

real data

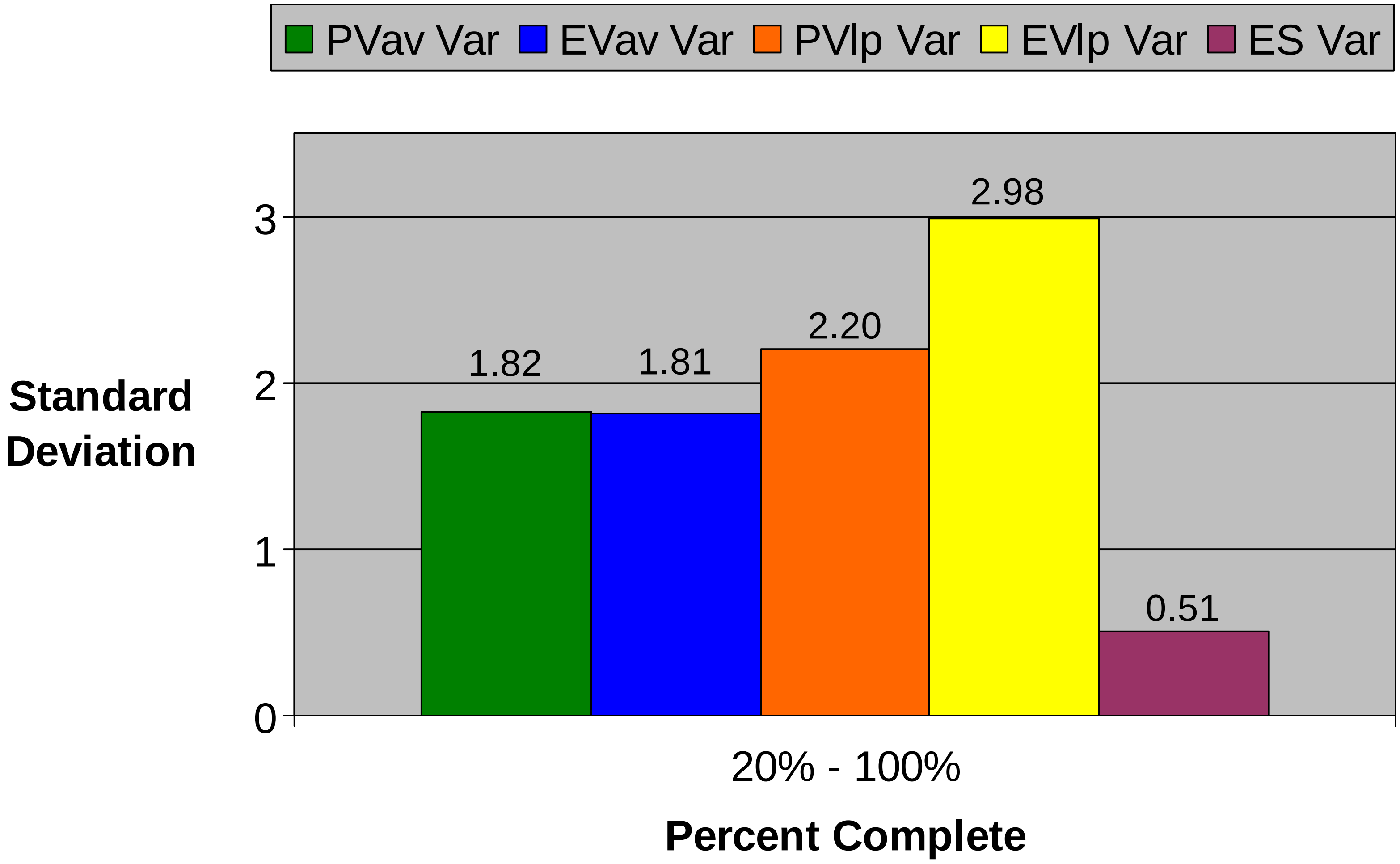


Comparison of Forecasting Accuracy



Comparison of Forecasting Accuracy

real data



Forecasting Comparison Results

- ES is seen to perform well over the entire period of performance for the project.
- The bar chart comparing the accuracy of forecasting of the EVM and ES methods over three ranges of performance is a succinct compelling graphic.
- For this project data, ES forecasting is considerably better than any of the EVM time conversion methods.

Research evidence indicates the ES method is superior to the EVM forecasting methods.

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

ES Calculation Exercise

- Complete Early & Late Worksheets (tan areas only) by calculating *ES, SV(t), SPI(t)*
- Earned Schedule Formulas:
  - ES = C + I
  - C = Number of time increments of PMB for EV ≥ PV_n
  - $I = (EV – PV_C) / (PV_{C+1} – PV_C)$
  - AT = Actual Time (number of periods from start)
  - Schedule Variance: SV(t) = ES – AT
  - Schedule Performance Index: SPI(t) = ES / AT

Use the "Tulsa ES Calculation Exercise" spreadsheet

ES Exercise - Worksheet

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PV($)	105	200	515	845	1175	1475	1805	2135	2435	2665	2760	2823
EV($)	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
PV($)	105	200	515	845	1175	1475	1805	2135	2435	2665	2760	2823	------	------	------
EV($)	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 Calculation Exercise

ES Calculation Exercise

ES Exercise - Answers

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PV($)	105	200	515	845	1175	1475	1805	2135	2435	2665	2760	2823
EV($)	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)

ES Exercise - Answers

	Year 01												Year 02		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
PV($)	105	200	515	845	1175	1475	1805	2135	2435	2665	2760	2823	------	------	------
EV($)	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	3.773	4.667	5.467	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	-0.227	-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)

Demonstrate – ES Calculator

Earned Schedule Calculator

ES Calculator v1b

Demonstrate – Forecasting

Earned Schedule Calculator

With forecasting added

ES Calculator & Forecast

Demonstrate – Prediction

ES Prediction Calculator

TSPI Prediction Calculator

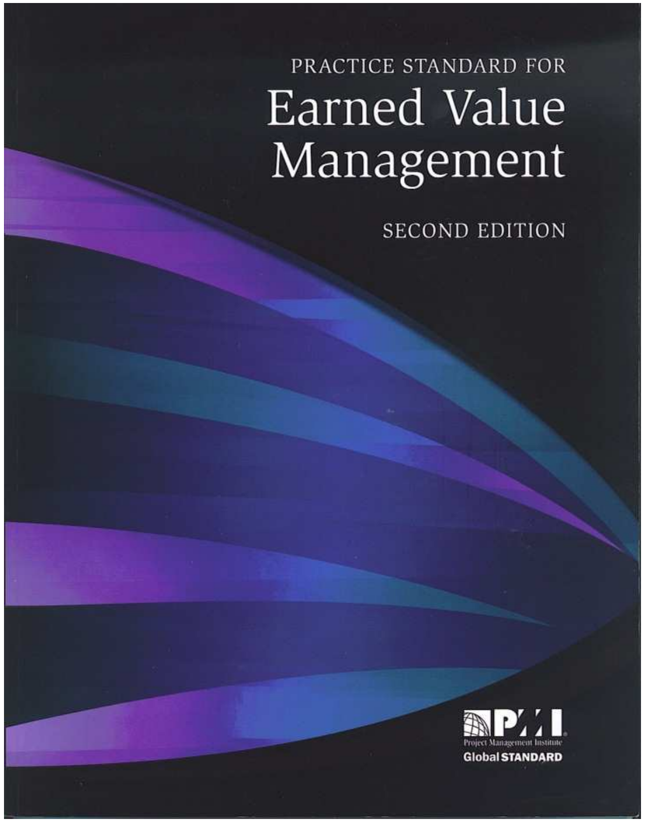
ES Usage & Propagation

Application Expanding Globally

Evidence of Earned Schedule Usage			
Application	USA	Lockheed-Martin Boeing Booze-Allen-Hamilton Government & Defense	Projects are generally extremely large, running for a decade or more and costing in excess of $1 Billion.
	Australia UK Belgium Kazakhstan India	Private & Defense Network Rail & Defense Fabricom (GDF-SUEZ) Petroleum Development Building Construction	
University Coursework	USA	George Washington University, Drexel, University of Houston, University of Nevada (Reno), West Virginia University, Pennsylvania State University	
	non-USA	University of Ghent (Belgium), Australian National University	
Books	USA	*Earned Schedule* by Walter H. Lipke *Project Management Theory and Practice* by Dr. Gary L. Richardson *The Earned Value Maturity Model* by Ray W. Stratton *A Practical Guide to Earned Value Management, 2nd Edition* by Charles & Charlene Budd *Project Management Achieving Competitive Advantage* by Jeffrey K. Pinto *Practice Standard for Earned Value Management* by Project Management Institute	
	non-USA	*Measuring Time: Improving Project Performance Using Earned Value Management* by Dr. Mario Vanhoucke *Earned Schedule - an emerging Earned Value technique* issued by UK APM EVM SIG	

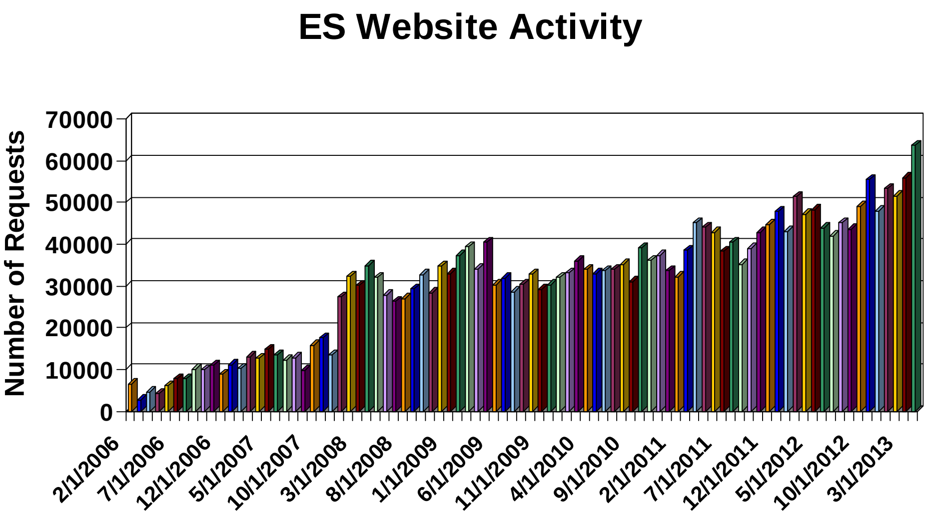
PMI EVM Practice Standard

- Inclusion of *Earned Schedule* into PMI EVM Practice Standard, 2nd Edition (2011)
- Appendix D, “Schedule Analysis Using EVM Data,” provides ES theory and practical application to example project.



Earned Schedule Website

- Established February 2006
- Contains *News, Papers, Presentations, ES Terminology, ES Calculators, Concept Description*
- Identifies *Contacts, Analysis Tools & Training Sources* to assist with application
- The activity growth of the website has been <u>astounding</u> – beginning at **4,000** is now more than **60,000** requests per month



EVM/ES Training Sources

- Management Technologies
  - www.mgmt-technologies.com
- Performance Management Associates
  - www.pmassoc.com
- Project Management Training Institute
  - www.4pmti.com

EVM Analysis Tools with ES

SUPERTECH Project Management

- ***EVEngine***^{TM} – Project Control software from Supertech Project Management:
  - Comprehensive Earned Value Performance Management, including Earned Schedule.
  - ***EVEngine***^{TM} is an add-on for Microsoft Excel.
  - Uses scheduling data from Microsoft Project and Primavera.
  - 30-Day no obligation evaluation contact EVPM@suptec.us.

EVM Analysis Tools with ES

- ProTrack
  - Developed in Belgium by OR-AS (Dr. Vanhoucke, Van Acker)
  - Check http://www.protrack.be for news and availability
  - Check http://www.or-as.be for general information
  - Free subscription to newsletter available at www.or-as.be website home page
- Project Schedule Analyzer add-on for MS Project
  - Developed by Dr. Robert Van De Velde
  - Incorporates *Schedule Adherence,* and other advanced concepts
  - Made available in April 2008: www.projectflightdeck.com

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 “bottom-up” schedule analysis
- Application is growing in both small and large projects
- Practice recognized by PMI in EVM Practice Standard
- Resource availability enhanced with ES website and Wikipedia
- Research indicates ES superior to other methods

Advanced Methods

Advanced Methods

- Critical Path Application
- Schedule Adherence
- Rework Forecast
- Statistical Methods
- Small Projects
- Longest Path Forecasting

Critical Path Application

Critical Path Application

- Critical Path – the sequence of planned tasks having the longest duration
- Traditionally, management focuses on performance of the CP …believing by so doing project duration is minimized
- Schedulers forecast completion by adding the remaining planned task durations of the CP to the actual duration
  - The forecast doesn’t take into account the schedule performance efficiency of the accomplished work

Critical Path Application

- Are there ways ES can be used to analyze CP performance?
- EVM provides no measure of CP performance …EV accrual can come from any task
- First method – compare IEAC(t) to the CP forecast
  - BAH has used this method – execution problems were identified earlier from the ES forecast
  - Henderson achieved similar results
  - Although method is not applied directly to CP …it does infer that typical CP forecasting is unreliable

Critical Path Application

- Second method – use the CP tasks as if they comprise the project
  - Create PMB from CP tasks only
  - Use EV from these tasks to compute ES
  - Compare $SPI(t)_{CP}$ to SPI(t) for total project
    - When $SPI(t)_{CP} \cong SPI(t)$ – balanced execution, minimizes project duration
    - When $SPI(t)_{CP} \neq SPI(t)$ – problems can be expected, duration forecast will likely worsen
  - Method provides management additional information regarding critical and non-critical performance …and brings more focus to network schedule execution

Critical Path Application

- Both methods are considerably less effort than bottom up analysis
  - The significant analysis effort advantage offered by IEAC(t) & $SPI(t)_{CP}$ methods does not mean to imply that detailed schedule analysis should never be performed …a bottom-up remaining schedule estimation should be performed, as well, for critical decisions
- Traditionally, EVM has been restricted to cost performance analysis …ES provides the link to extend EVM to CP performance analysis

Demonstrate – Critical Path Analysis

Exercise – CP Analysis

- Using performance data and ES calculator (v1b):

1) Calculate schedule performance ($SPI(t)_C$) and forecast (IEAC(t)) for CP and total project (TP) for each period
2) Compare IEAC(t) values at each period. What can be inferred from your analysis?

Exercise – CP Analysis Data

	Measure	0	1	2	3	4	5	6	7	8	9	10	11	12
		••• Performance Period •••												
Total Project	PVp	0	5	5	35	30	40	30	20	5	10	5	0	0
	PVc	0	5	10	45	75	115	145	165	170	180	185	185	185
	EVp	0	0	4	16	43	27	18	31	16	9	15	3	3
	EVc	0	0	4	20	63	90	108	139	155	164	179	182	185
	ACp	0	0	5	20	52	35	20	37	22	10	20	5	3
	ACc	0	0	5	25	77	112	132	169	191	201	221	226	229
Critical Path 1-4-8-10	PVp	0	5	5	5	5	5	5	10	5	5	5	0	0
	PVc	0	5	10	15	20	25	30	40	45	50	55	55	55
	EVp	0	0	4	8	10	3	0	12	8	0	10	0	0
	EVc	0	0	4	12	22	25	25	37	45	45	55	55	55
	ACp	0	0	5	10	12	5	0	15	12	0	14	0	0
	ACc	0	0	5	15	27	32	32	47	59	59	73	73	73

Exercise – CP Analysis Results

	Indicator	0	1	2	3	4	5	6	7	8	9	10	11	12
		••• Performance Period •••												
Total Project	CPIp	xxx	xxx	0.800	0.800	0.827	0.771	0.900	0.838	0.727	0.900	0.750	0.600	1.000
	CPIc	xxx	xxx	0.800	0.800	0.818	0.804	0.818	0.822	0.812	0.816	0.810	0.805	0.808
	SPI(t)p	xxx	0.000	0.800	1.486	1.314	0.775	0.450	0.975	0.700	0.450	1.950	0.500	0.600
	SPI(t)c	xxx	0.000	0.400	0.762	0.900	0.875	0.804	0.829	0.813	0.772	0.890	0.855	0.833
	SPIp	xxx	0.000	0.800	0.457	1.433	0.675	0.600	1.550	3.200	0.900	3.000	xxx	xxx
	SPIc	xxx	0.000	0.400	0.444	0.840	0.783	0.745	0.842	0.912	0.911	0.968	0.984	1.000
	IEAC(t)	xxx	xxx	25.00	13.13	11.11	11.43	12.44	12.07	12.31	12.95	11.24	11.70	12.00
Critical Path 1-4-8-10	CPIp	xxx	xxx	0.800	0.800	0.833	0.600	xxx	0.800	0.667	xxx	0.714		
	CPIc	xxx	xxx	0.800	0.800	0.815	0.781	0.781	0.787	0.763	0.763	0.753		
	SPI(t)p	xxx	0.000	0.800	1.600	2.000	0.600	0.000	1.700	1.300	0.000	2.000		
	SPI(t)c	xxx	0.000	0.400	0.800	1.100	1.000	0.833	0.957	1.000	0.889	1.000		
	SPIp	xxx	0.000	0.800	1.600	2.000	0.600	0.000	1.200	1.600	0.000	2.000		
	SPIc	xxx	0.000	0.400	0.800	1.100	1.000	0.833	0.925	1.000	0.900	1.000		
	IEAC(t)	xxx	xxx	25.00	12.50	9.09	10.00	12.00	10.45	10.00	11.25	10.00	xxx	xxx

- Balanced performance at period 2; thereafter TP > CP forecasts
- Management protected CP while ignoring alternate paths

Schedule Adherence

Schedule Adherence

- Recall the initiatives to improve project performance and quality over the last 25 years: SPC, TQM, SEI CMM®, and ISO 9001
- What was their message?

Undisciplined project execution leads to inefficient performance and defective products.

- Then …doesn't it make sense to measure how well the plan (process) is being followed?

Measuring Schedule Adherence

- We want to know:

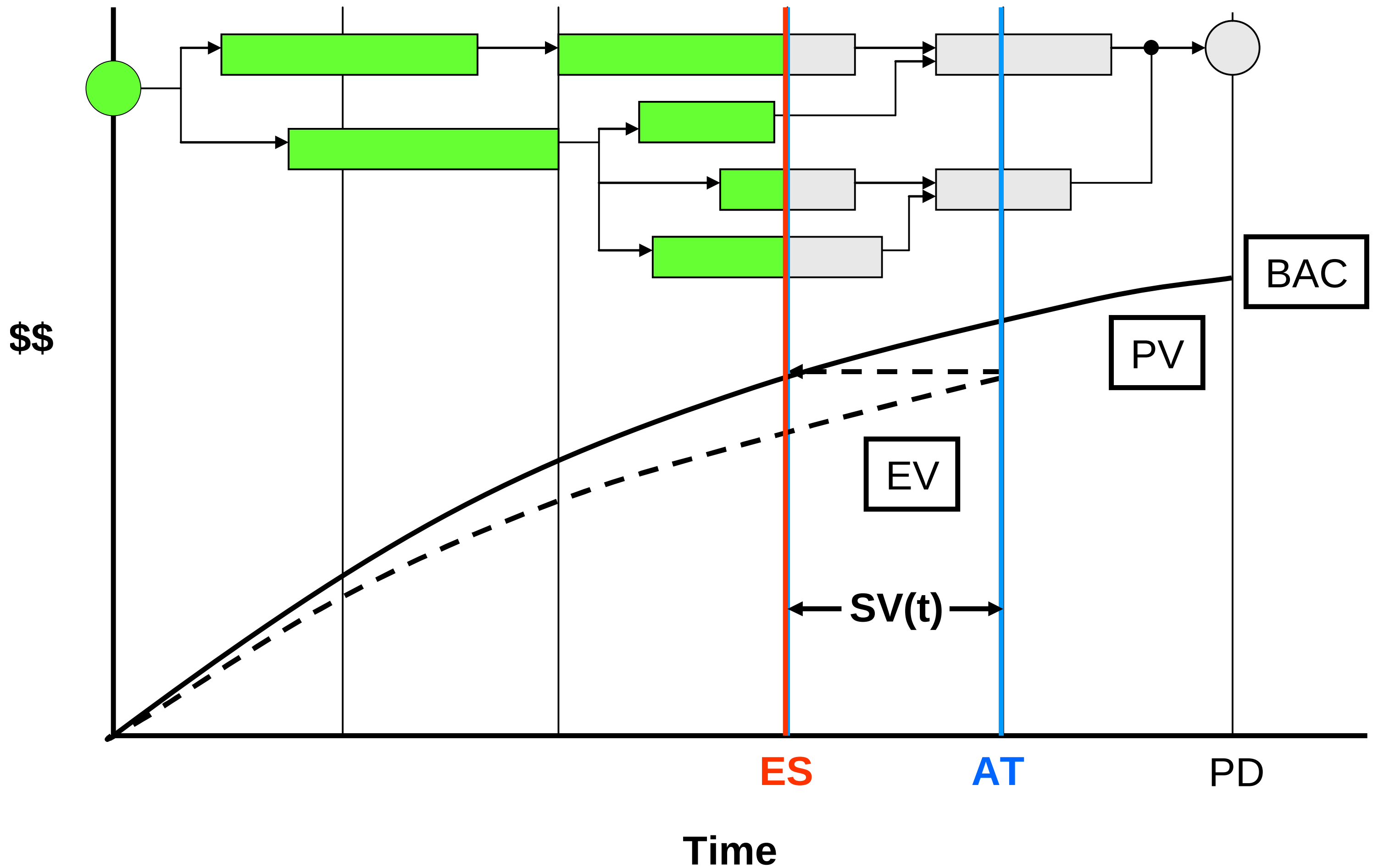
Did the accomplishment match exactly the expectation from the planned schedule?
- "Schedule Adherence" -

- Earned Schedule provides a means to measure Schedule Adherence

Measuring Schedule Adherence

- The connection between ES and the PMB is remarkable …*regardless of the project's position in time, we can know what <u>should</u> have been accomplished*
- For a claimed amount of EV at a status point AT, the portion of the PMB which should be accomplished is identified by ES

Measuring Schedule Adherence

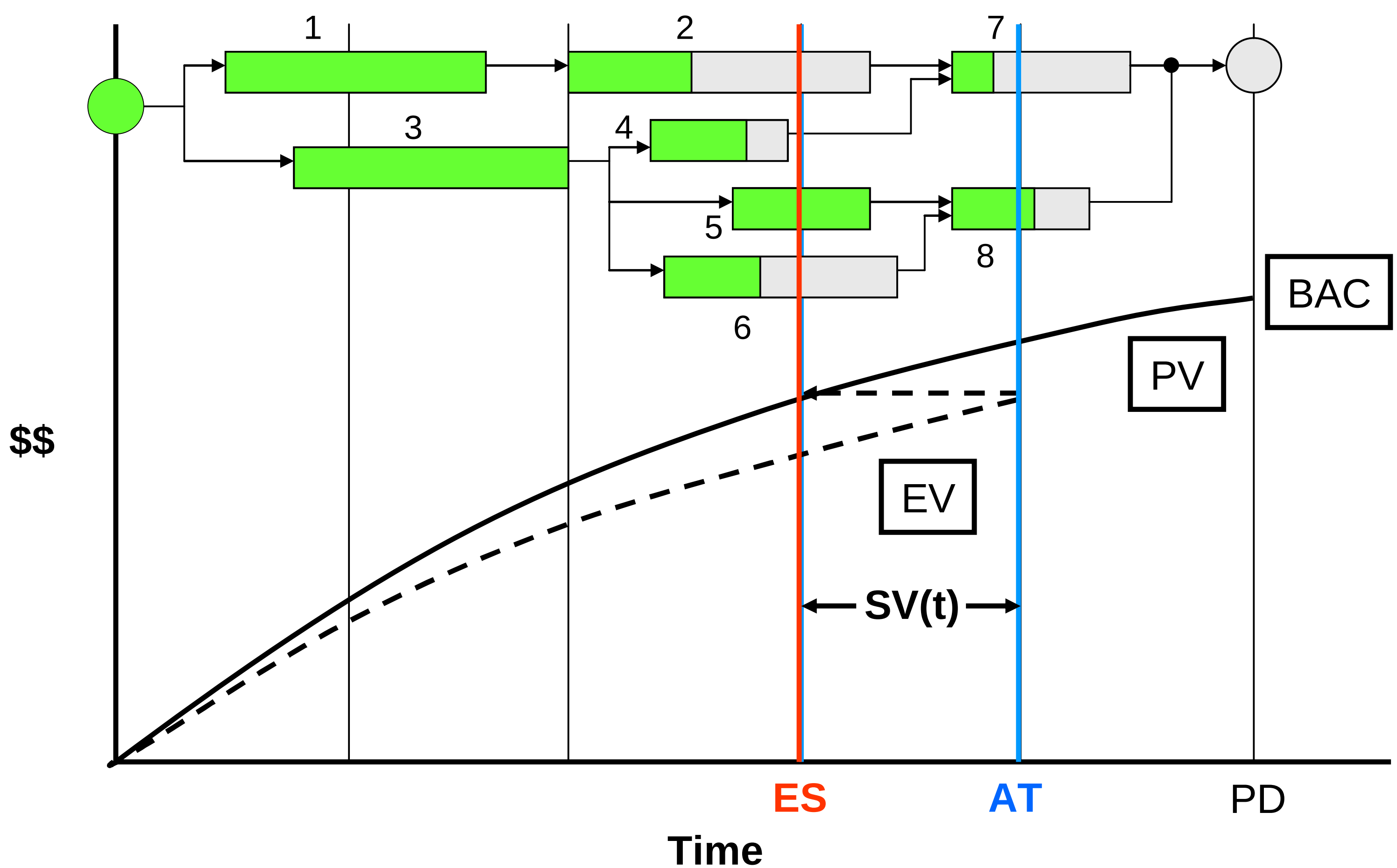


Measuring Schedule Adherence

- It is more likely performance is not synchronous with the schedule …EV is not being accrued in accordance with the plan
- The next chart is an example …the EV accrued is the same amount as shown on the previous chart, but has a different distribution

What do you see?

Measuring Schedule Adherence



Measuring Schedule Adherence

- Tasks behind – indicates the possibility of impediments or constraints
- Tasks ahead – indicates the likelihood of future rework
- Both, lagging & ahead cause poor performance efficiency …ahead performance is most likely caused by the lagging tasks

Concentrating management efforts on alleviating impediments & constraints will have the greatest positive impact on project performance

Measuring Schedule Adherence

- Ahead tasks are frequently performed without complete information
- Performers must anticipate the inputs from the incomplete preceding tasks
- When anticipation is incorrect a significant amount of rework is created
- Complicating the problem the rework created for a specific task will not be recognized for a time ….until all of the inputs are known or the output is incompatible for a dependent task

Measuring Schedule Adherence

- By measuring the portion of the EV accrued that is congruent with the planned schedule we can have an indicator for controlling the process
- Schedule Adherence is defined as:

$$P = \Sigma EV_j \,/\, \Sigma PV_j$$

  where the subscript j denotes the identity of the tasks comprising the planned accomplishment
- The value of ΣPV_j is equal to the EV accrued at AT
- ΣEV_j is the amount of EV for the j tasks, limited by the value of the corresponding PV_j

Measuring Schedule Adherence

- Recall the question …

> ***Did the accomplishment match exactly the expectation from the planned schedule?***

- The P-Factor is the indicator for answering the question
- Characteristics of the P-Factor
  - Its value must be between 0.0 and 1.0
  - P = 1.0 at project completion
  - P = 0.0 indicates accomplishment out of sequence
  - P = 1.0 indicates perfect conformance to schedule

Measuring Schedule Adherence

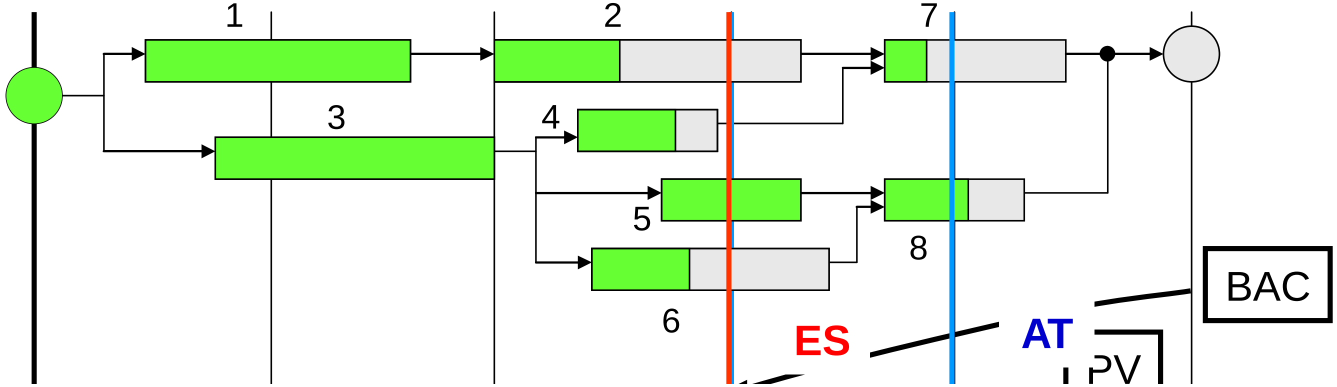
- When the value of P is much less than 1.0 the PM has a strong indication of an impediment, overload of a constraint, or poor process discipline
- When P has a value very close to 1.0, the PM can feel confident the schedule is being followed ….and that milestones and interim products are occurring in the proper sequence

The PM now has an indicator which enhances the description of project performance portrayed by EVM & ES

Example Application

- Notional data has been created to illustrate the application of *Schedule Adherence*
- The task numbers in the table are associated with the numbering shown on the chart of the network schedule
- By calculating the difference between PV@ES and EV@AT, impediments/constraints (I/C) and rework (R) can be identified to specific tasks

Example Application



Task	PV	PV@ES	EV@AT	EV - PV	I/C or R
1	10	10	10	0	
2	12	9	5	-4	I/C
3	10	10	10	0	
4	5	5	3	-2	I/C
5	5	2	5	+3	R
6	8	4	3	-1	I/C
7	7	0	1	+1	R
8	5	0	3	+3	R
Total	62	40	40	0	

Example Application

- Three tasks identified as lagging: 2, 4, and 6
- PM should investigate these tasks for removal of impediments or alleviation of constraints
- Should no impeding problem be found, the PM has reason to suspect poor process discipline from one or more members of the project team
  - It may be discovered that an employee is insufficiently skilled or trained
  - The employee to obtain a satisfactory performance review performed a down stream task because he knew how to do it
  - In this instance …..Who caused the problem?

Example Application

- Tasks identified for potentially creating rework are: 5, 7, and 8.
- Clearly tasks 7 & 8 are at risk of rework because some or all of the required inputs are absent
- The potential for rework is not so obvious for task 5. …it is not synchronous with the schedule, but the needed inputs are complete
  - By working ahead the worker presumes that his work is unaffected by other facets of the project
  - Subtle changes to task requirements often occur as more detail becomes known

Example Application

- What is the value of the P-Factor for this example?

Task	PV	PV@ES	EV@AT	EV - PV	I/C or R
1	10	10	10	0	
2	12	9	5	-4	I/C
3	10	10	10	0	
4	5	5	3	-2	I/C
5	5	2	5	+3	R
6	8	4	3	-1	I/C
7	7	0	1	+1	R
8	5	0	3	+3	R
Total	62	40	40	0	

- It is seen that PV@ES = EV@AT … PV@ES identifies the tasks which should be in-work/complete: 1 through 6

Example Application

Task	PV	PV@ES	EV@AT	EV - PV	I/C or R
1	10	10	10	0	
2	12	9	5	-4	I/C
3	10	10	10	0	
4	5	5	3	-2	I/C
5	5	2	5	+3	R
6	8	4	3	-1	I/C
7	7	0	1	+1	R
8	5	0	3	+3	R
Total	62	40	40	0	

- Sum of EV@AT for 1 thru 6 is equal to 36 …but the amount of EV for task 5 is +3 with respect to its corresponding task PV ...and thus, $\Sigma EV_j = 36 - 3 = 33$
- The P-Factor can now be calculated:

$$P = \Sigma EV_j / \Sigma PV_j = 33 / 40 = 0.825$$

Example Application

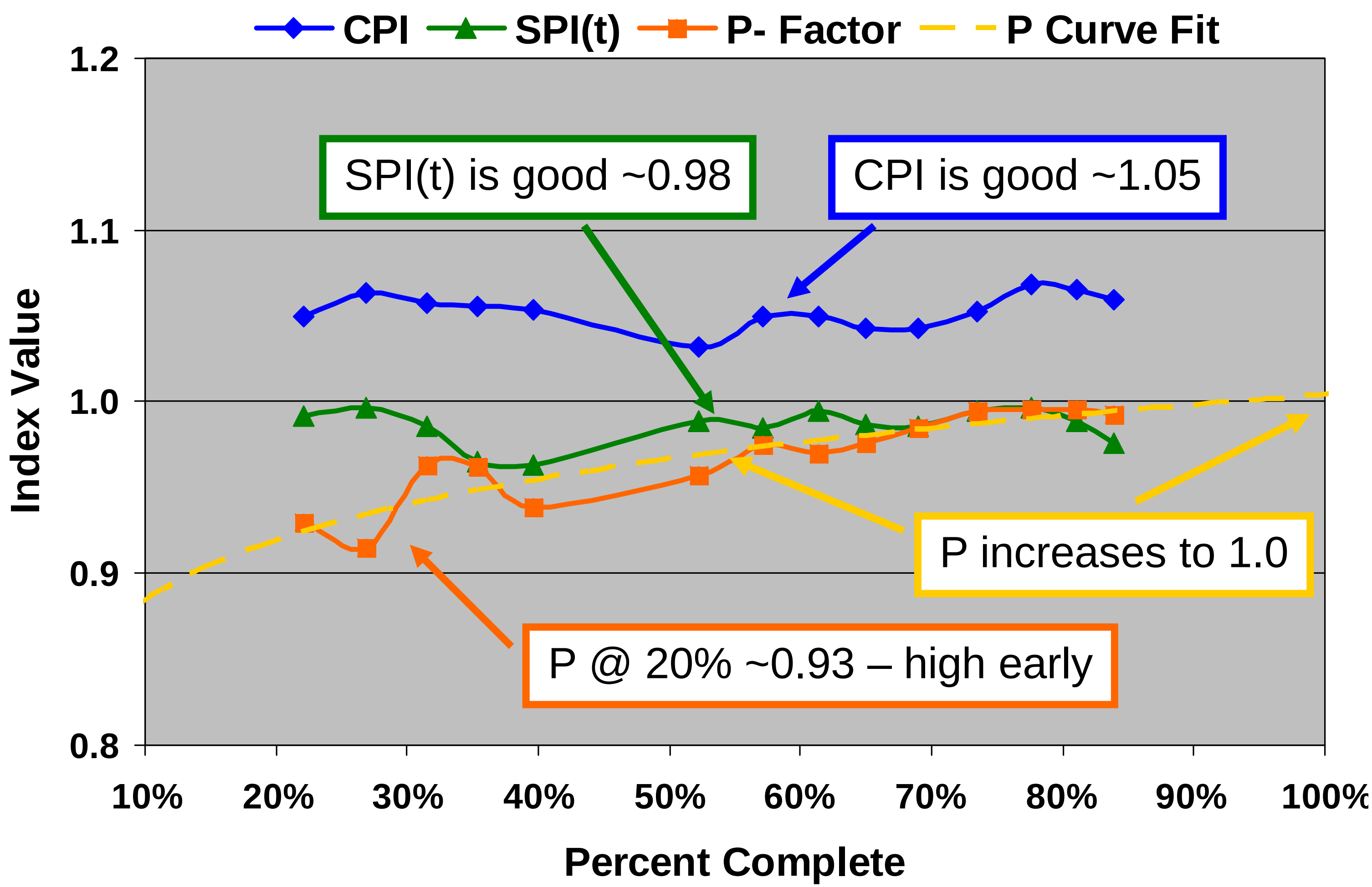
- From the value of P …~80 percent of the execution is in conformance with the schedule
- Presuming all of the claimed accomplishment not in agreement with the schedule requires rework, i.e. 7 units ….then:
  - ~18 percent of claimed EV requires rework
  - Without a large amount of MR, successful completion is unlikely
  - The PM has much to do to save this project …however, without the P-Factor indicator and the analysis ES facilitates, it is unclear as to what he/she should investigate and take action to correct

Real Data Results

- The next chart is a graph of CPI, SPI(t) and the P-Factor versus Percent Complete using actual project data
- Observe the following:
  - Values of P from 20% through 40% complete
  - Values of CPI & SPI(t) throughout
  - Overall behavior of the P-Factor

What can be said about this project?

Real Data Results



Real Data Results

- The outcome forecast is the project will complete under budget and slightly past the planned date …*a successful project*
- A logical conjecture is ...when the planned schedule is closely followed output performance is maximized …the project has the greatest opportunity for success
- Also …when the indicators are all good, especially early in the project, we can deduce the project planning was excellent, as well as management and employee performance

Schedule Adherence Summary

- Earned Schedule, an extension to EVM for schedule performance analysis, is extended further …creating a useful tool for PMs
- EV and ES with the PMB are used to develop the concept of *Schedule Adherence*
  - Measure for Schedule Adherence: $P = \Sigma EV_j / \Sigma PV_j$
  - Identification of Impediments/Constraints & Rework
- High value of P leads to …
  - Maximum performance for Cost & Schedule
  - Greater understanding of excellent project planning

Final Remarks

- Some EVM experts & practitioners believe that schedule analysis is possible only through detailed examination of the network schedule
- *Schedule Adherence* is a PM tool for process control not available from traditional analysis of the network schedule
- Use of the P-Factor measure is encouraged …a calculator is available from the ES website

Rework Forecast

Background

- Rework has a negative impact on the likelihood of project success
- A significant portion of rework is caused by deviating from the project plan and its associated schedule
- The concept of schedule adherence provides an approach to increase project control and minimize the cost impact of rework

Background

- Several causes of rework other than imperfect schedule adherence
  - Poor planning
  - Defective work
  - Poor requirements management
  - Schedule compression
  - Over zealous quality assurance
- We are focused on rework from imperfect schedule adherence – only

Derivation of Rework

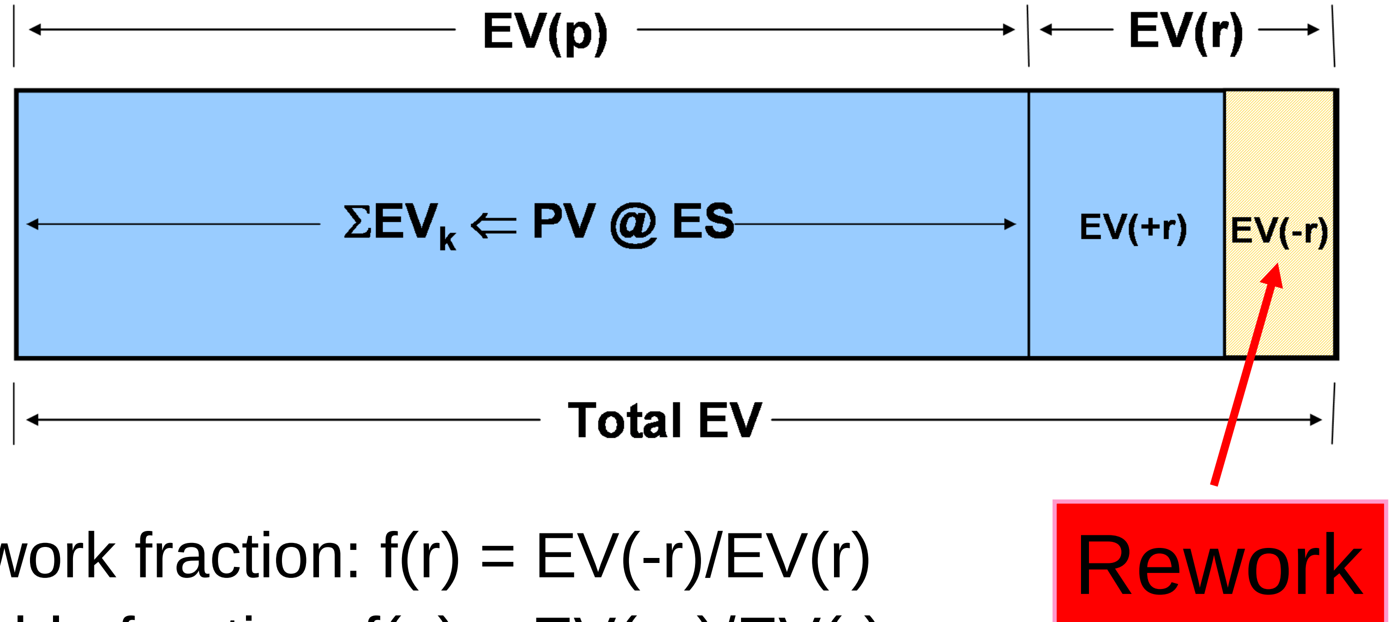
- Fundamental relationships:
  - EV accrued = ΣEV_j @ AT = ΣPV_k @ ES
  - EV earned in concordance with the schedule:

    $EV(p) = \Sigma EV_k$ @ $AT = P \bullet EV$

    ...where $EV_k \leq PV_k$ and $P = \Sigma EV_k / \Sigma PV_k$
  - EV earned not in agreement with the schedule:

    $EV(r) = EV – EV(p) = (1 – P) \bullet EV$
- A portion of EV(r) is unusable and requires rework

Derivation of Rework



- Rework fraction: f(r) = EV(-r)/EV(r)
- Usable fraction: f(p) = EV(+r)/EV(r)

where EV(r) = EV(-r) + EV(+r)

and f(r) + f(p) = 1

Derivation of Rework

- Using the definitions we can describe rework, R, in terms of EV, P, and f(r):

$$R = EV(-r) = f(r) \bullet (1 - P) \bullet EV$$

  - P and EV are obtainable from status data
  - Project team's ability to interpret requirements increases with work accomplishment
  - Conditions for f(r):
    - f(r) = 1 @ C = 0 and f(r) = 0 @ C = 1

      where C = EV/BAC, i.e. the fraction complete
    - Rework fraction decreases as EV increases
    - Rate of f(r) decrease becomes larger as EV $\Rightarrow$ 1

Computation Methods

- The value computed for R represents the cost of rework forecast for the remainder of the project due to the present value of P
- Although of some interest, P is not particularly useful for PMs
- Regardless of effort invested to improve, P increases as project progresses and concludes at 1.0 at completion
- Thus, R does not yield trend information, nor can it lead to a forecast of total cost of rework

Computation Methods

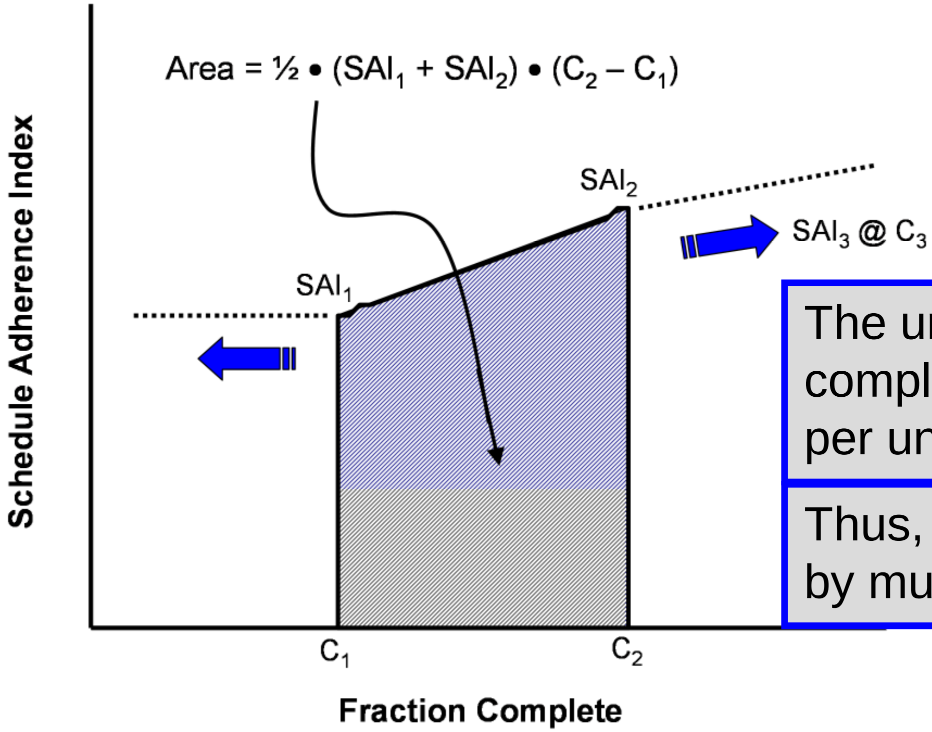
- R can be transformed to a useful indicator by dividing by the work remaining (BAC – EV):

  SAI = R/(BAC – EV)

  where SAI = Schedule Adherence Index
- SAI is useful for detecting trends …thus a management tool for gauging actions taken
  - SAI increasing with EV $\Rightarrow$ SA worsening
  - SAI decreasing with EV $\Rightarrow$ SA improving

Computation Methods

- Having SAI facilitates the calculation of rework within a performance period



The units of the area is fraction complete times cost of rework per unit of budget

Thus, rework cost is computed by multiplying the area by BAC

Computation Methods

- To obtain the rework cost for period n:

  $R_p(n) = BAC \bullet [½ \bullet (SAI_n + SAI_{n-1}) \bullet (C_n – C_{n-1})]$

  For n = 0 and N: SAI = 0.0

- The cumulative accrual is the sum of the periodic values:

  $R_{cum} = \Sigma R_p(n)$

- The formula for total rework forecast is:

  $R_{tot} = R_{cum} + SAI \bullet (BAC – EV)$

Computation Methods

- To clarify what R_{tot} represents, it is the forecast of actual cost for rework from imperfect execution of the schedule
- From experience, rework cost is closely aligned with planned cost
- Generally, rework does not experience the execution inefficiencies incurred in the initial performance of the tasks

Notional Data Example

Status Point	1	2	3	4	5	6
EV	$14	$37	$58	$82	$97	$113
P	0.082	0.208	0.247	0.337	0.371	0.431
Status Point	**7**	**8**	**9**	**10**	**11**	
EV	$125	$137	$157	$177	$185	
P	0.520	0.650	0.822	0.955	1.000	

- P values are very poor and do not exceed 0.8 until nearly 85% complete …normally P is greater than 0.8 by 20% complete
- Because P is poor we should expect rework to be large with respect to BAC

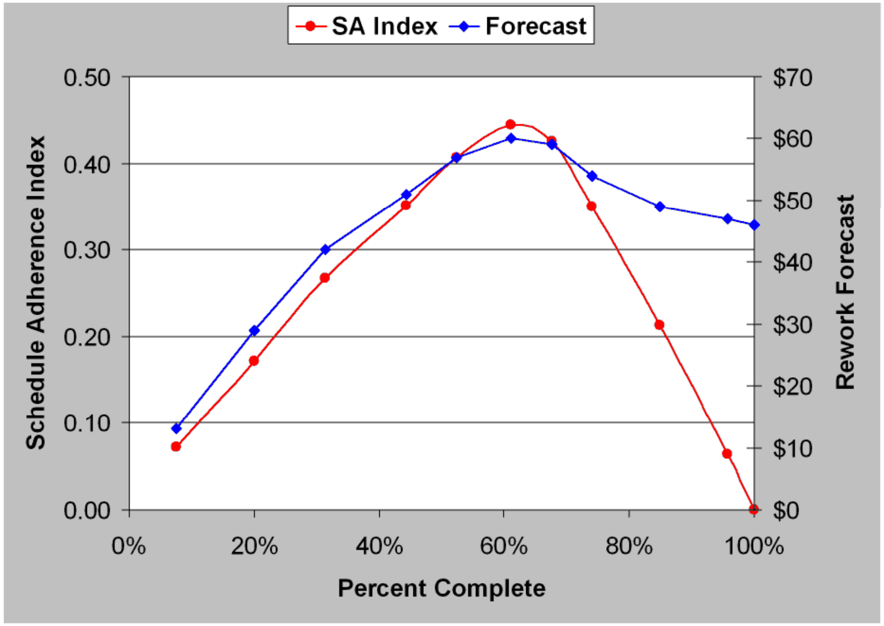
Notional Data Example

Status Point	1	2	3	4	5	6
Percent Complete	7.6%	20.0%	31.4%	44.3%	52.4%	61.1%
SA Index	0.072	0.171	0.267	0.351	0.407	0.444
Rework Forecast	$13	$29	$42	$51	$57	$60

Status Point	7	8	9	10	11	
Percent Complete	67.6%	74.1%	84.9%	95.7%	100.0%	
SA Index	0.425	0.350	0.213	0.064	0.000	
Rework Forecast	$59	$54	$49	$47	$46	

- SAI increases until ~60% complete and then improves as the project moves to completion
- Rework forecast rapidly increases until ~30% complete, then at a slower rate peaks at $60 when 61% is reached …from there forecast decreases slightly to finish at $46 or about 25% of BAC ($185)

Notional Data Example



- SAI improves greatly after its peak value, but rework forecast improves only marginally
- Why? – there is less work remaining

Real Data Example

Status Point	1	2	3	4	5
EV	$549,707	$668,776	$784,508	$881,288	$986,529
P	0.930	0.915	0.963	0.962	0.939
Status Point	6	7	8	9	10
EV	$1,299,880	$1,422,033	$1,526,842	$1,617,976	$1,716,130
P	0.957	0.975	0.970	0.975	0.984
Status Point	11	12	13	14	
EV	$1,826,991	$1,930,651	$2,015,852	$2,088,967	
P	0.994	0.995	0.996	0.993	

- P-Factor is high initially and increases to 0.995 by 75% complete
- CPI = 1.05 & SPI(t) = 0.98 – both are comparatively high
- Synergy between high values of P and high index values

Real Data Example

Status Point	1	2	3	4	5
Percent Complete	22.1%	26.9%	31.5%	35.4%	39.6%
SA Index	0.017	0.026	0.013	0.015	0.028
Rework Forecast	$37,483	$53,697	$31,945	$35,577	$55,671

Status Point	6	7	8	9	10
Percent Complete	52.2%	57.2%	61.4%	65.0%	69.0%
SA Index	0.027	0.018	0.023	0.021	0.014
Rework Forecast	$54,401	$43,519	$49,221	$46,812	$41,443

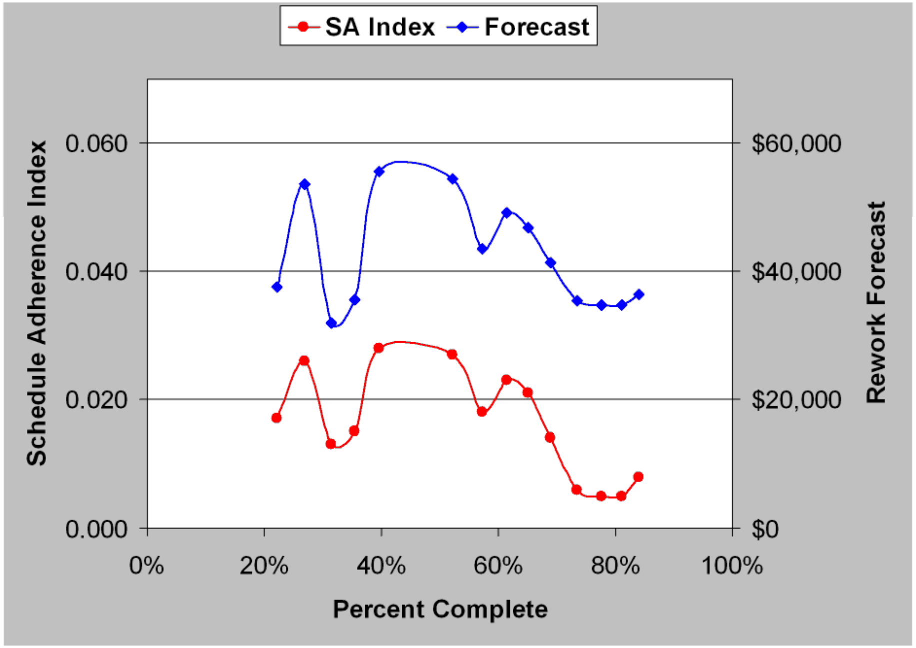
Status Point	11	12	13	14	
Percent Complete	73.4%	77.6%	81.0%	84.0%	
SA Index	0.006	0.005	0.005	0.008	
Rework Forecast	$35,349	$34,821	$34,754	$36,377	

- With P values very high, SAI values are extremely low, as expected

Real Data Example

- Other observations
  - SAI highest value = 0.028, lowest = 0.005
  - SAI values for real data as much as 89 times lower than for notional data
  - Average forecast value of rework = $42K or 1.7% of BAC ($2.5M)
  - Standard deviation of forecast values = $8300, thus high bound = $42K + 3 • $8.3K ≅ $67K

Real Data Example



- SAI & rework plots have negative trends showing improvement after 40% complete
- Assuming trend continues, rework will conclude at less than $40K, 1.6% of BAC

Summary

- From the introduction of schedule adherence there has been a desire for the ability to forecast the cost of rework
- The forecast capability was long thought to be too complex for practical application
- The presentation has shown calculations are not that encumbering
- SAI was introduced and shown to be integral to computing the forecast rework

Summary

- The application of SAI and rework forecasting was discussed for notional and real data
- SAI is proposed to be a viable PM tool for control of project performance, thereby enhancing the probability of a successful project
- Including SAI and R_{tot} at status reviews can be expected to heighten senior level attention to rework and process

Final Remarks

- To encourage the application and uptake of the SAI and rework forecasting method a tool for trialing is available at the calculators page of the Earned Schedule website:

SA Index & Rework Calculator

The calculator produces values and graphs for the accrual and forecast of the total cost for rework, along with the value of the EV for work accomplished out of sequence. The calculator includes instructions and example data for trial use.

Statistical Methods - Planning

Statistical Planning for Risk

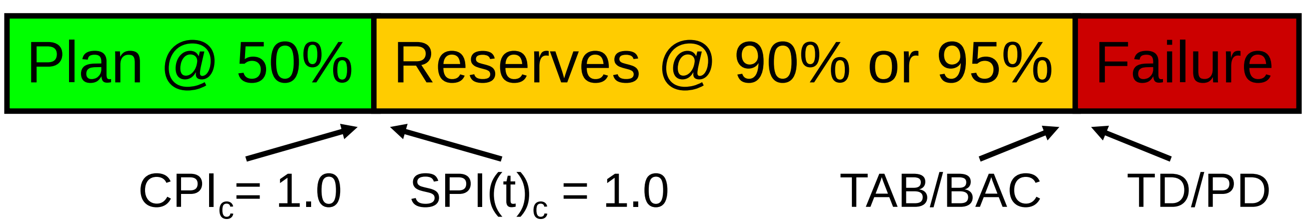
- An objective of project planning is to mitigate the foreseen risks with sufficient reserves in both cost and schedule duration.
- The application of the mathematics of statistics to the cost and schedule indicators from EVM and ES provides a method for linking risk to reserves and the forecast probability of project success.

Planning Tenets

- Plan for cost & schedule success at 50% probability
- Reserves are established to achieve a high level of confidence – 90% or 95%
- Reserves and probability of success are used to link management with competitive bid

Normalizing Cost/Schedule

- Cost – BAC & TAB
- Schedule – PD & TD
  - PD = planned duration
  - TD = total duration
- Difference between planned and total is the reserve
- Ratios TAB/BAC & TD/PD define worst acceptable performance



Performance Interpretation

- Performance Outcome

$xPI_c^{-1} \leq 1.0$	Plan Achieved
$1.0 < xPI_c^{-1} \leq xR$	Customer Satisfied
$xR < xPI_c^{-1}$	Exceed Allocation

where xPI = CPI or SPI(t)

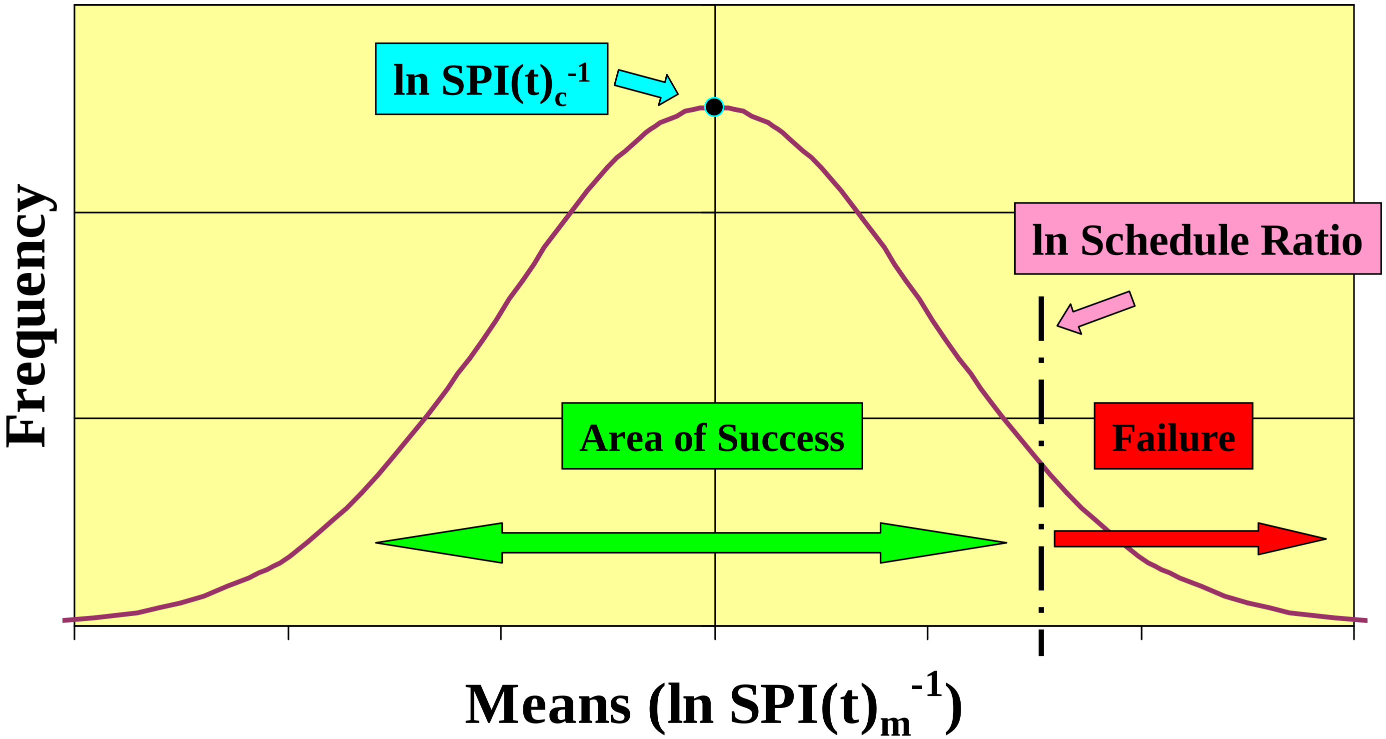
xR = TAB/BAC or TD/PD (Cost or Schedule Ratio)

PD = Planned Duration

TD = Total Duration

Probability of Success

- Below is a graphic example using schedule measures



Planning Data & Calculation

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

Planning Data & Calculation

- Calculation

  PS ⇨ Z (use Normal Distribution Tables or Excel)

  $Z = (\ln xR - \ln xPI(t)_c^{-1}) / \sigma_m$

  where $xPI(t)_c^{-1} = 1.0$ for plan

  $xR = \text{antilog}(Z * \sigma_m)$

  Cost: CR = TAB/BAC ⇨ TAB = CR ∗ BAC

  Management Reserve = (CR – 1) ∗ BAC

  Schedule: SR = TD/PD ⇨ TD = SR ∗ PD

  Schedule Reserve = (SR – 1) ∗ PD

Example Calculation

- Data: $\sigma_H = 0.4$, BAC = \$1M, n = 36, PS = 90%
- Calculation:

  $\sigma_m = 0.4 / \sqrt{36} = 0.0667$

  PS = 90% $\Rightarrow$ Z = 1.2816

  Cost Ratio = antilog (1.2816 $*$ 0.0667)

  = 1.0892

Management Reserve = (1.0892 – 1) $*$ \$1M

= \$89,200

- Does this amount of reserve cause the bid to be non-competitive? …Can we accept more risk with a lower probability of success?

Summary & Comments

- Simple statistical methods link probability of success to reserves …to bid competitiveness …and management decisions
- Makes use of historical data …and creates need for repository containing valid data
- Creates an awareness during planning of the connection between risk and competitiveness
- Separates risk resource planning from task estimates for both cost and duration

Statistical Planning Calculator

- *Statistical Planning Calculator* available at the ES website
- Example data included for familiarization and experimentation

Statistical Methods - Forecasting

Statistical Forecasting

- An objective of project management is to have the capability to reliably predict cost and schedule outcomes
- The application of statistical methods to the cost and schedule indicators from EVM and ES is a well-founded means for providing the project management objective

Forecasting with EVM & ES

- IEAC = BAC / CPI
  - IEAC = Independent Estimate at Completion
  - BAC = Budget at Completion
  - CPI = Cost Performance Index

    = EV / AC
- IEAC(t) = PD / SPI(t)
  - IEAC(t) = IEAC(time)
  - PD = Planned Duration
  - SPI(t) = Schedule Performance Index (time)

    = ES / AT

Application of Statistics

- Available EVM & ES project performance data facilitates the application of statistical methods
- Confidence Limits can be used for
  - Forecasting range of possible outcomes
  - Management information, especially for when re-negotiation is necessary
- Wide-spread application will require statistical tools tailored to EVM/ES data

Statistical Method

- Confidence Limits: the range of possible values which encompass the true value of the mean, at a specified level of confidence
- Mathematically for an infinite population

$$CL = Mean \pm Z * \sigma/\sqrt{n}$$

Mean = estimate of average from the sample

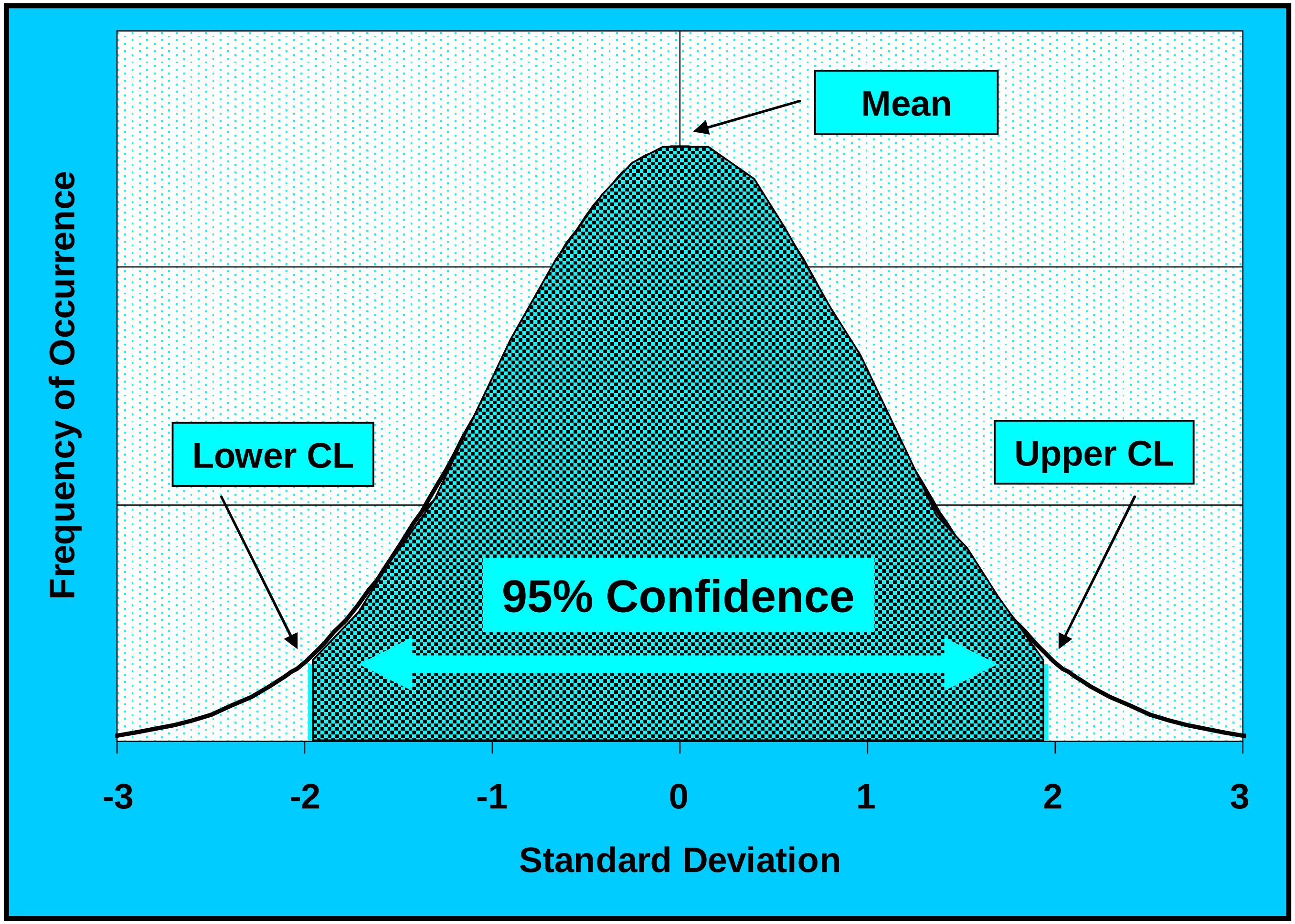
Z = value related to prescribed area within the Normal distribution

[generally 90% or 95% level of confidence]

σ = estimate of the Standard Deviation

n = number of observations in the sample

Confidence Limits



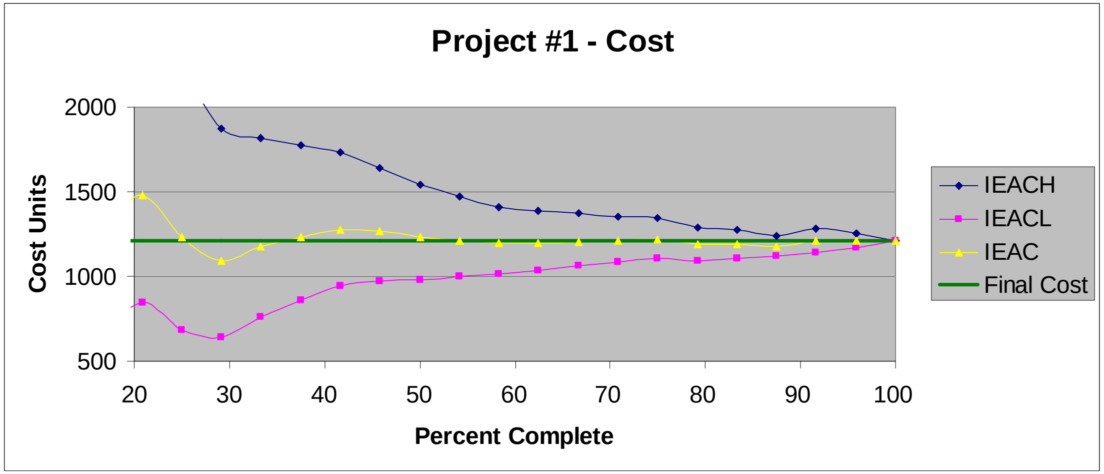
Complexity Elements

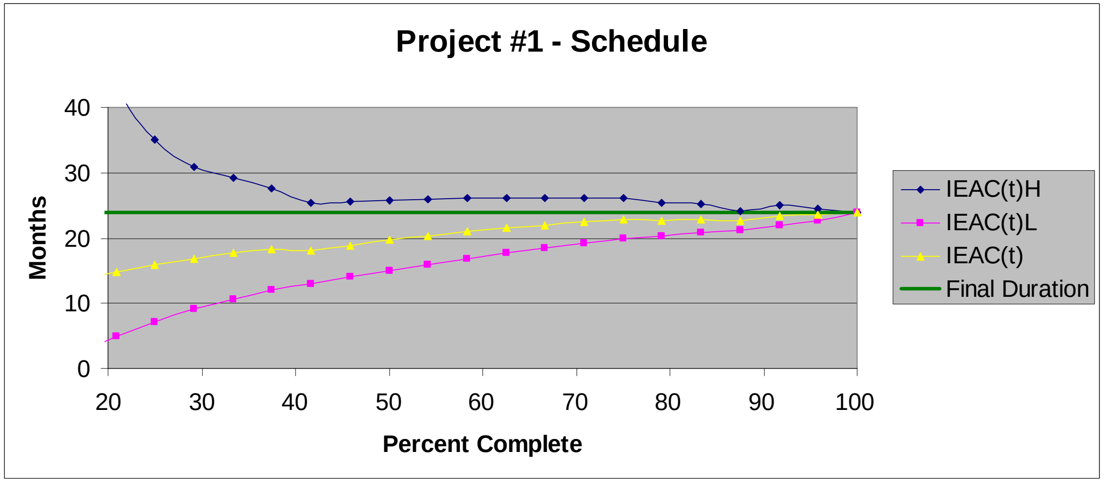
- Normality of Data
  - CPI & SPI(t) distributions appear lognormal
  - Mean is logarithm of cumulative value of index
  - $\sigma = \sqrt{(\Sigma(\ln \text{period index(i)} - \ln \text{cum index})^2 / (n - 1))}$
- Finite Population
  - $AF_C = \sqrt{((BAC - EV) / (BAC - (EV/n)))}$
  - $AF_S = \sqrt{((PD - ES) / (PD - (ES/n)))}$
- Fewer than 30 Observations
  - Use Student-t Distribution

Use of Confidence Limits

- Confidence Limits of the performance indexes, using the finite population adjustment, have been shown to produce reliable forecasts of bounds for cost and schedule outcomes
- $CL_{(\pm)} = \ln \text{index(cum)} \pm Z * (\sigma/\sqrt{n}) * AF$
- Forecast at Completion
  - $IEAC_{(\text{low or high})} = BAC / e\text{^}(CL_{(\pm)})$
  - $IEAC(t)_{(\text{low or high})} = PD / e\text{^}(CL(t)_{(\pm)})$

Example Forecast (90% Confidence – real data)





Project #1 Observations

- Difference between upper & lower CLs becoming smaller as percent complete increases
- CPI is very stable between 50% and 100%
- SPI(t) consistently worsens
  - $IEAC(t)_H$ beginning at 30% complete proved to be very close to the eventual final duration
- As a rule, of the three plots, the graph that is most horizontal is the best forecast

Final Remarks

- The method put forth is generally applicable and encouraged – independent of size or type of project
- The statistical method has the potential to greatly enhance management information for the purpose of project control
- Tool for trialing available at the calculators page of the Earned Schedule website (*Statistical Forecasting Calculator*)

Small Projects

Small Projects

- Conditions occurring for small, short duration, projects - *Stop Work and Down Time* - can cause error for ES indicators, and forecasts
- For large projects, these conditions for small portions of the project may not have much impact on the ES indicators and forecast values
- For small projects, the interrupting conditions will distort ES indicators and forecasts and possibly impact management decisions

Small Projects

- Down Time – *periods within the schedule where no work is planned*
  - Extends the planned period of performance
  - Management has the prerogative to work, instead
- Stop Work – *periods during execution where management has halted performance*
  - When management imposes a *Stop Work* the opportunity has been removed for accruing EV

Small Projects

- It is worthy to note that ES forecasts using the normal index values will always converge to the actual duration
- Well then …if this is the case …*Why bother?*
- The key point - when *Stop Work* and *Down Time* conditions occur, the normal indicators do not accurately portray performance and have the potential to cause inappropriate management decisions

Schedule Performance Indicators

- Relationship between normal and special schedule performance indicators – *Down Time affects SV(t), Stop Work affects SPI(t)*
  - $iSV(t)_{per} = SV(t)_{per} + DT_{per}$ *(DT_{per} = Down Time in the period)*
  - $iSV(t)_{cum} = SV(t)_{cum} + DT_T$ *(DT_T = Total Down Time)*
  - $iSV(t)_{cum}w/oDT = iSV(t)_{cum} – DT_R$ *(DT_R = Down Time remaining)*
  - $iSPI(t)_{per} = SPI(t)_{per}$
  - $iSPI(t)_{cum} = SPI(t)_{cum} \bullet (AT / (AT – SW))$

Note:
1) "Normal" refers to the results from the simple ES calculator
2) $iSV(t)_{cum}$w/oDT depicts position of the project should Down Time be compressed out

Forecasting Formula Derivation

- Simply stated – an initial forecast is made as if interrupting conditions are not present. The interruption effects are then added to this initial forecast as they occur
- The initial forecast is

  $$IEAC(t)_{sp1} = (PD – DT_T) / iSPI(t)_{cum}$$

  where DT_T = total number of down time periods
- The running total of stop work periods (SW) is added creating a second forecast expression

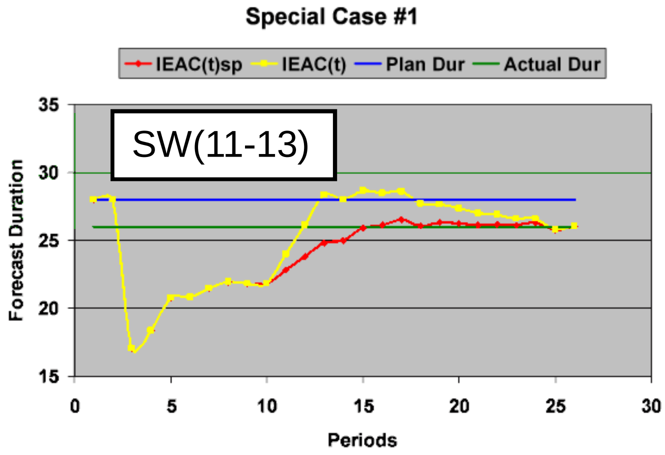
  $$IEAC(t)_{sp2} = (PD – DT_T) / iSPI(t)_{cum} + SW$$

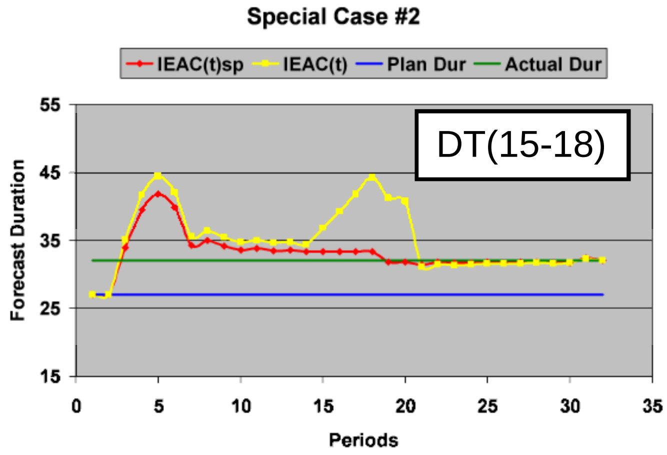
Forecasting Formula Derivation

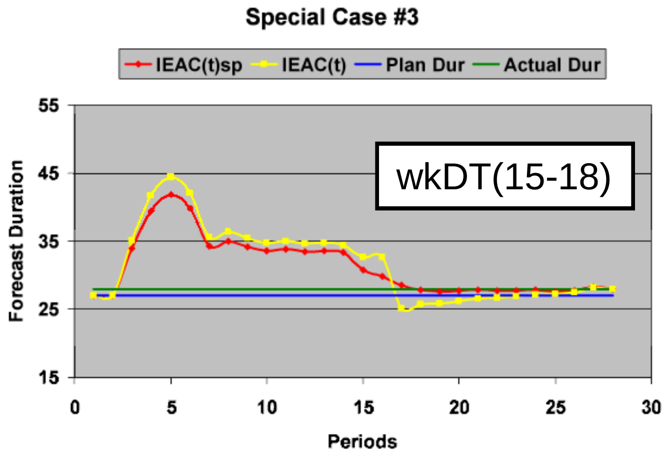
- Next DT_T is added. As down time periods occur they are totaled (DT_L) and subtracted.
- When $IEAC(t)_{sp2} < PD$, the number of down time periods between the forecast and PD are counted (DT_C) and subtracted
- The special forecasting formula becomes

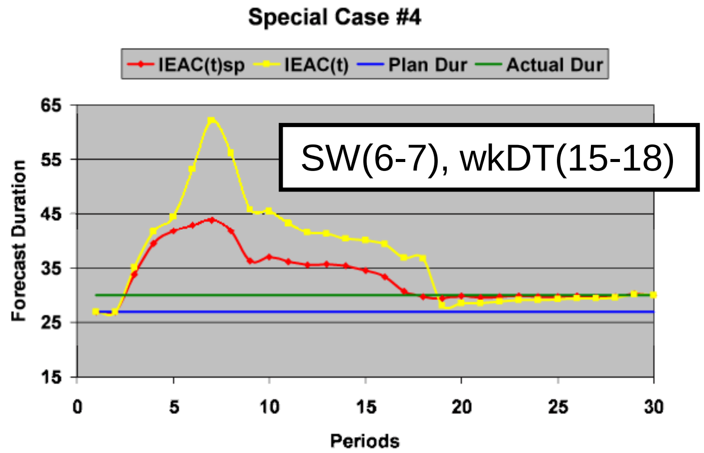
$$IEAC(t)_{sp} = (PD - DT_T) / iSPI(t)_{cum} + SW + DT_T - DT_L - DT_C$$

SW & DT Cases – Comparisons

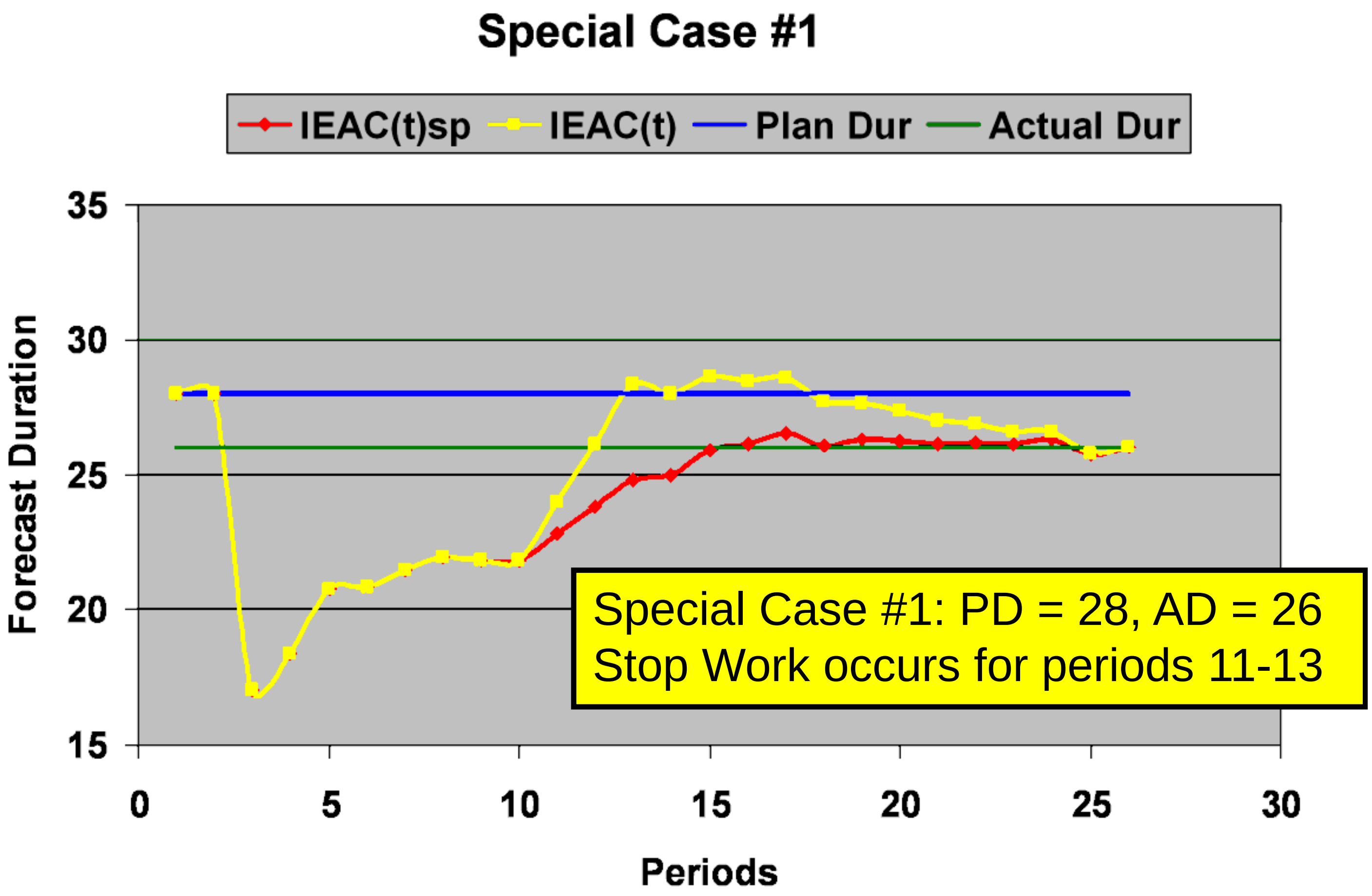




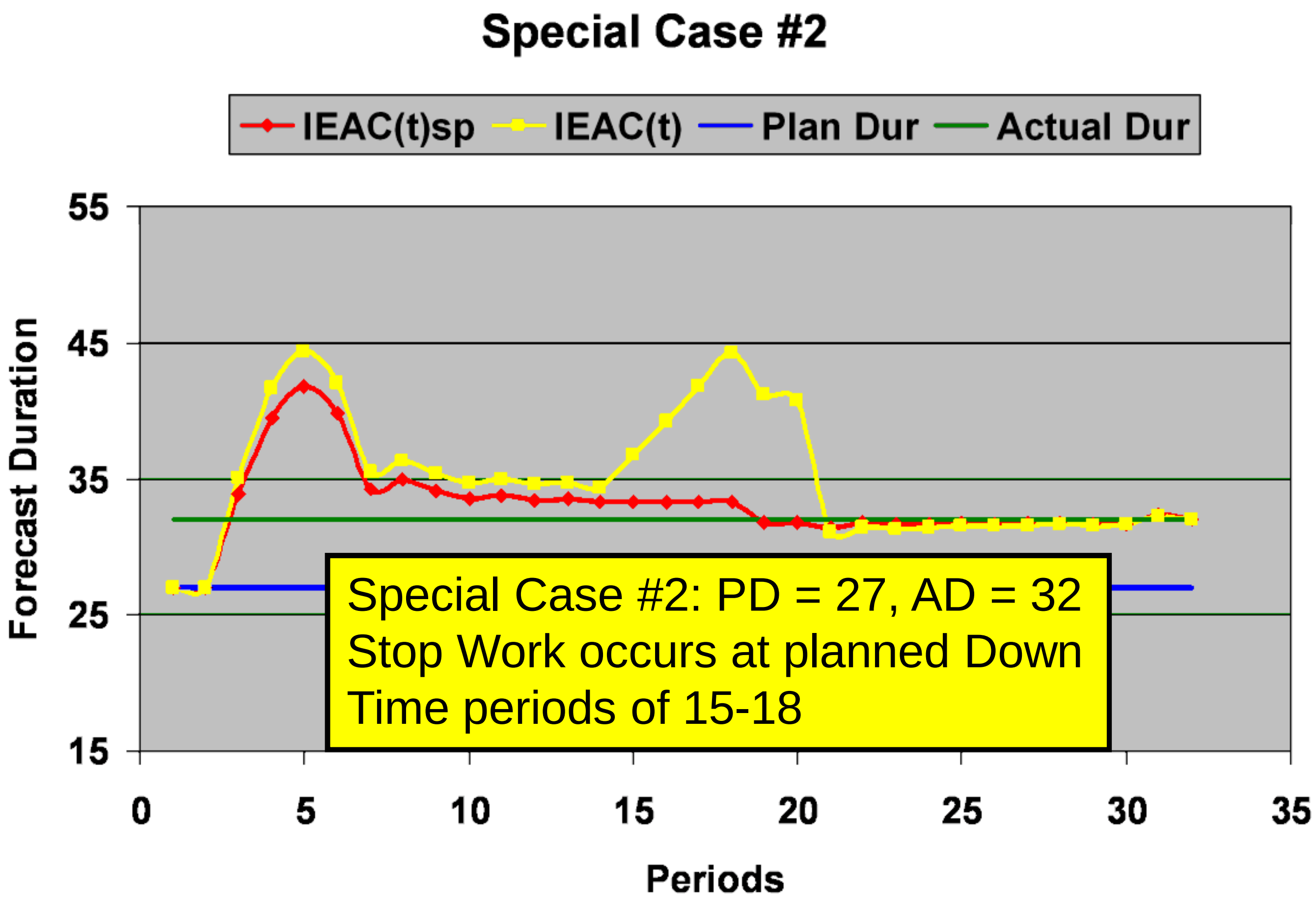




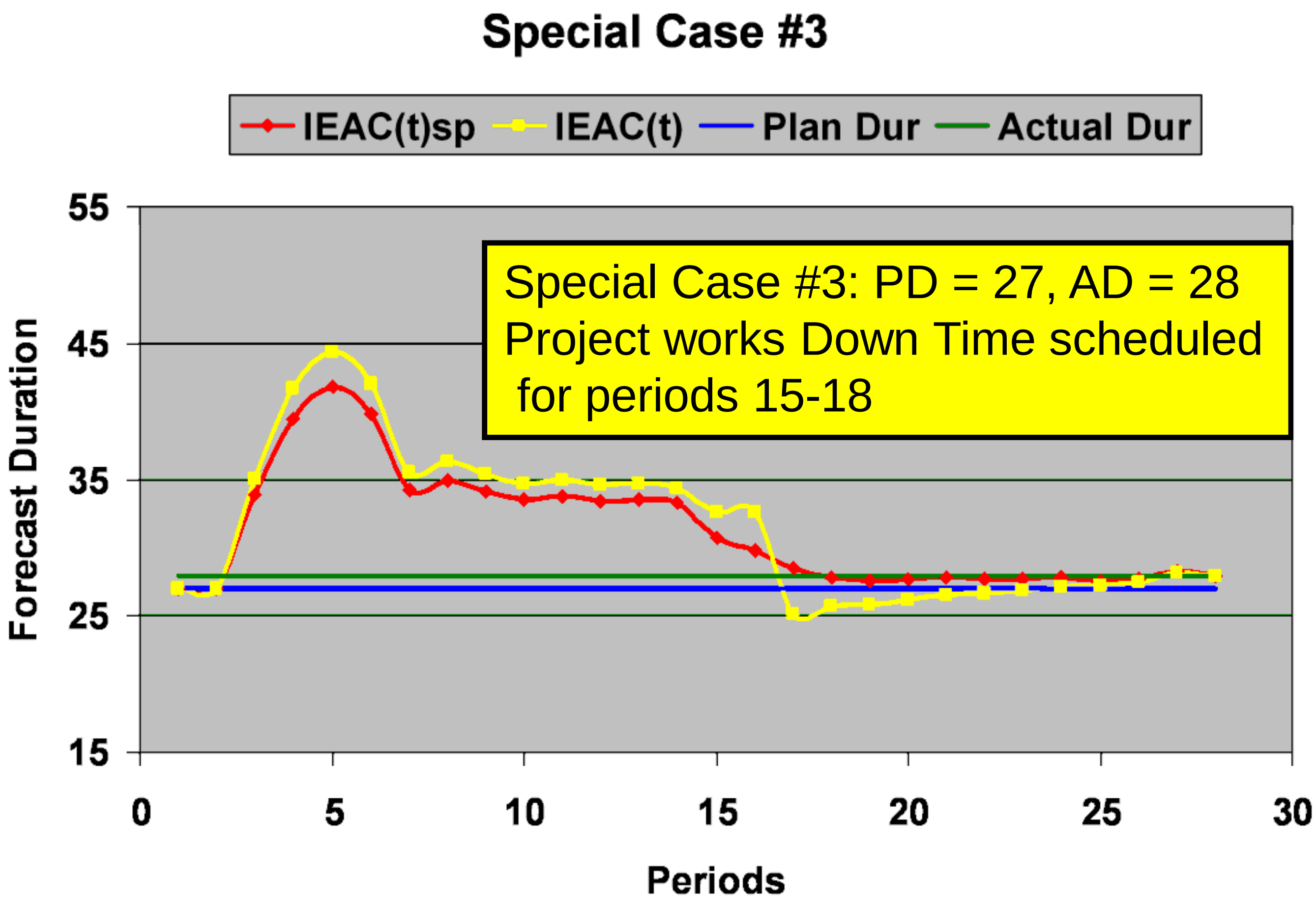
SW & DT Cases – Comparisons



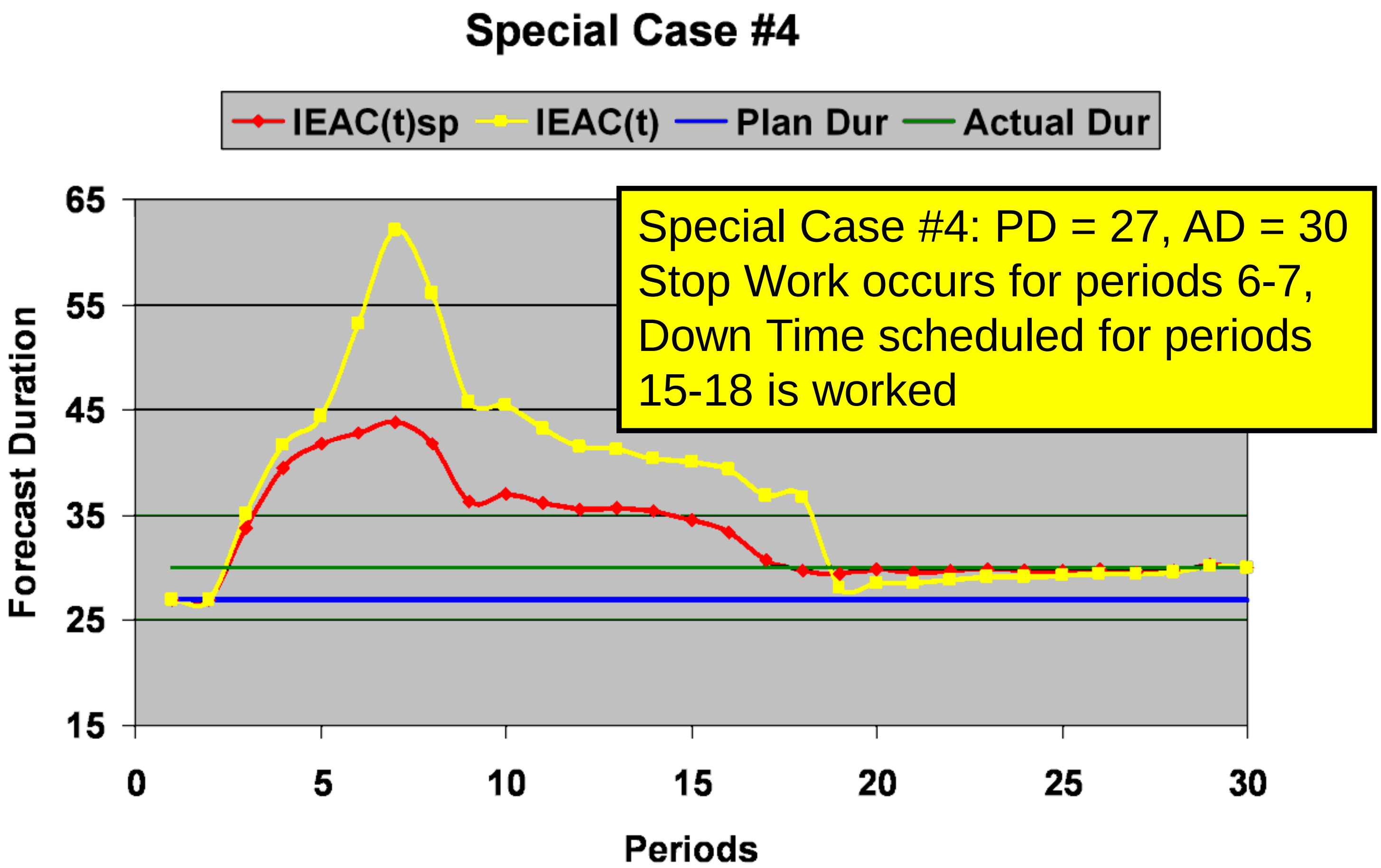
SW & DT Cases – Comparisons



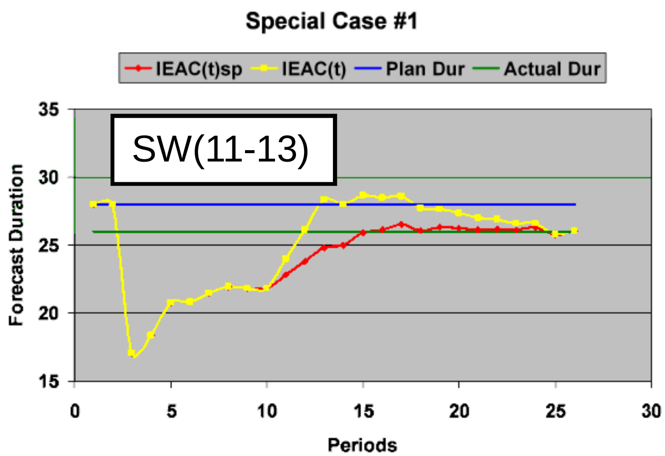
SW & DT Cases – Comparisons

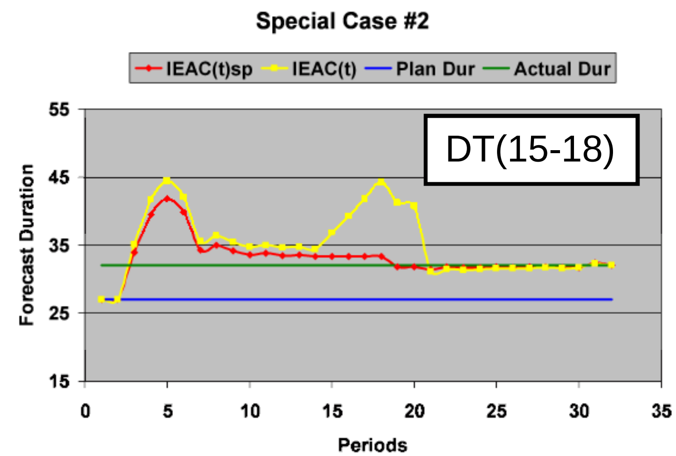


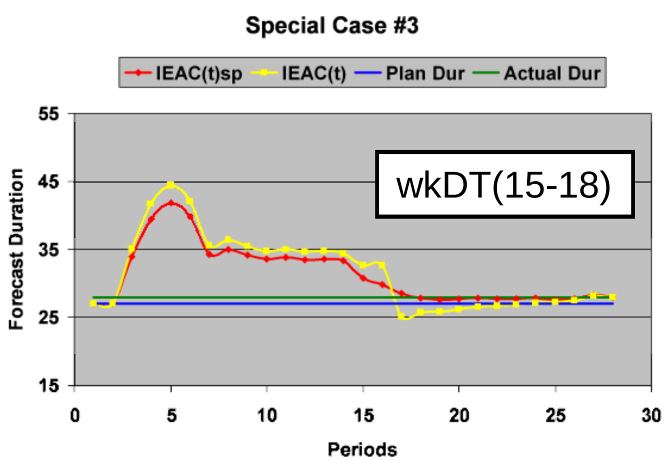
SW & DT Cases – Comparisons

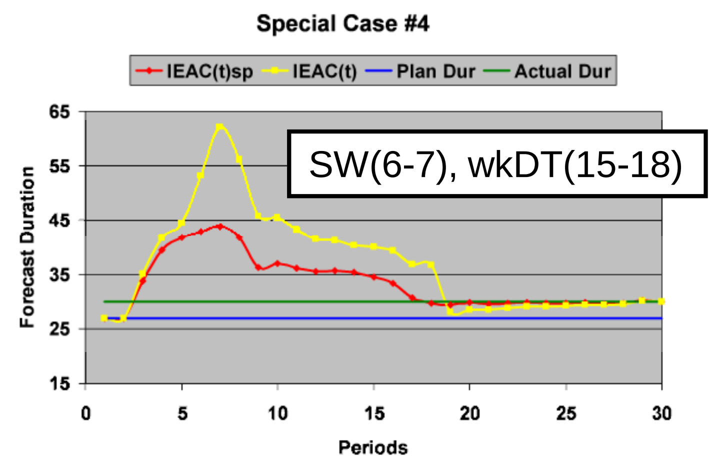


In each example it is observed that the special case forecast is as good or better than the normal ES forecast at every period of performance.









Small Projects Summary

- For small projects, the interrupting conditions, *Stop Work* and *Down Time,* distort ES indicators and forecasts and consequently can impact management decisions
- When interruptions of *Stop Work* and *Down Time* are encountered the special forecasting method can be expected to produce more reliable results
- To facilitate uptake of the special method a calculator *(ES Calculator vs1 (Special Cases))* is freely available from the ES website (www.earnedschedule.com)

Longest Path Forecasting

Longest Path Forecasting

- Practitioner and research evidence is compelling for applying ES project duration forecasting
- However, recent research indicates schedule topology impacts the "goodness" of the forecast … forecasts are more reliable for serial schedules than for parallel
- Combining ES forecasting with schedule risk analysis has been proposed to overcome the shortcoming …adding significant analysis effort

Is there a simpler method?

Longest Path Idea

- Given that the most reliable forecast occurs when schedule is serial

Is there a serial path we can use for analysis?

If YES, is the forecast from it an improvement?

- Concept of Longest Path is an extension of the ES application to the Critical Path
- Longest Path converges to the actual duration, just as does the ES forecast for the total project

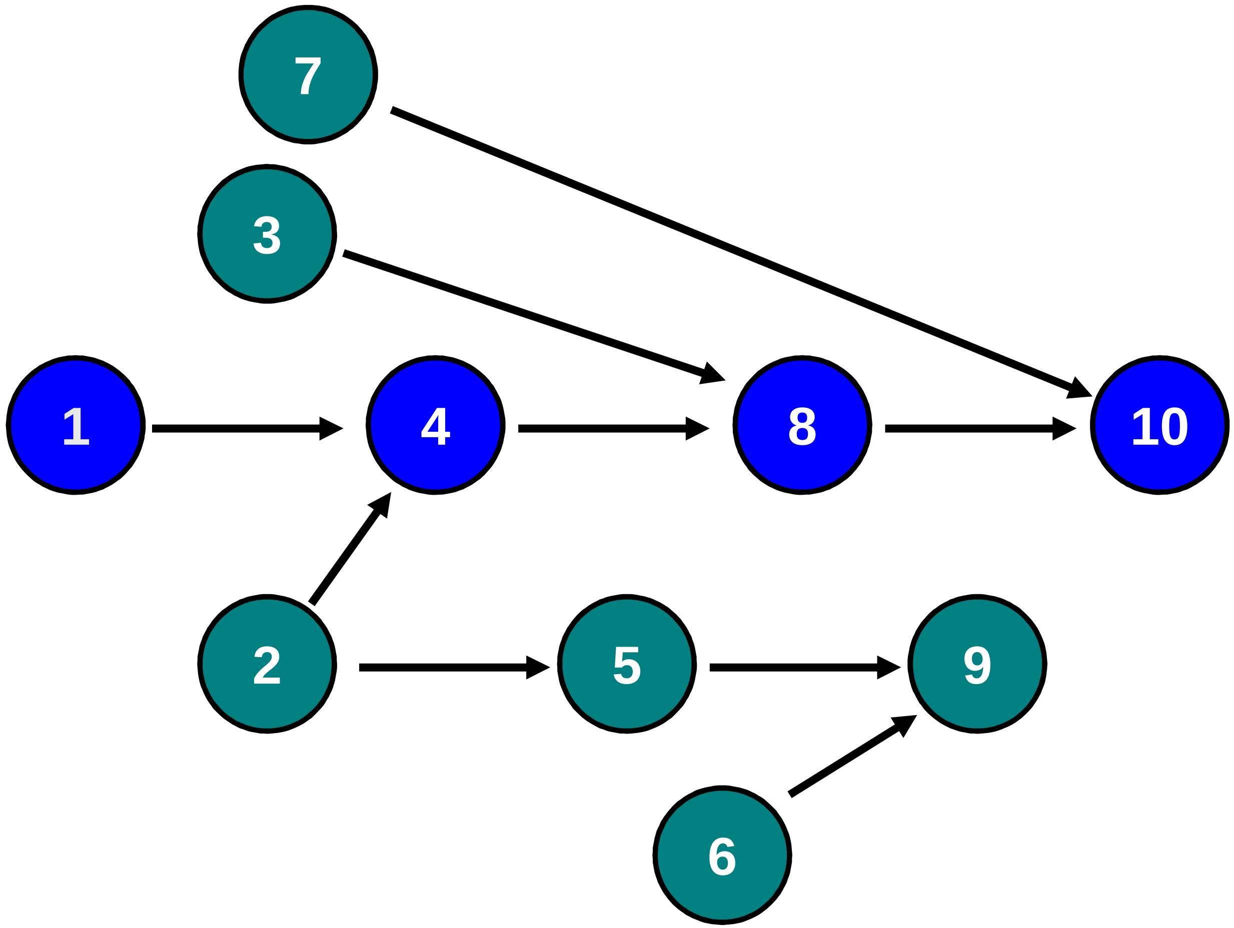
Longest Path Theory

- Longest Path (LP) converges to actual duration more rapidly than the ES forecast for the total project (ES-T)
- Thus, ES forecast using LP should be an improvement
- For the condition ES-LP > ES-T, the total project forecast may be considered a “lower bound” …a lingering question from the beginnings of ES
- If ES-LP is an improvement, the ES forecasting issue for parallel schedules is resolved …providing better and more direct information for project control

Longest Path Methodology

- Notional data used to examine the behavior of forecasts of ES-LP versus ES-T
- Ten task project created having, as the project progresses, several possible paths to completion
- Forecasts are made for the total project and the various paths
- The longest forecast from the paths in execution is LP
- The ES-LP forecast is compared to the ES-T forecast

Project Schedule Paths



Performance Analysis

- Execution of the various tasks does not necessarily coincide with the plan …voids are seen in the EV and PV data
- The project did not complete on the Critical Path
- Two paths completed two periods past the planned duration of 10 periods, 2-5-9 and 6-9

ES-LP versus ES-T Forecasts

Performance Path	**** **** **** Period **** **** ****											
	1	2	3	4	5	6	7	8	9	10	11	12
1-4-8-10		13.50	9.33	7.82	9.00	11.00	9.96	9.75	11.00	10.00		
2-4-8-10			28.67	10.89	10.00	12.67	10.51	10.00	11.33	10.00		
2-5-9				8.00	8.38	8.83	10.00	11.75	11.75	11.45	11.75	12.00
3-8-10			12.00	9.62	10.00	12.67	10.51	10.00	11.33	10.00		
7-10				12.75	12.24	12.75	11.57	10.78	11.40	10.00		
6-9						9.17	10.00	12.50	12.14	11.58	11.82	12.00
Total Project		13.50	9.75	9.33	10.03	11.12	10.74	11.29	11.81	11.11	11.64	12.00

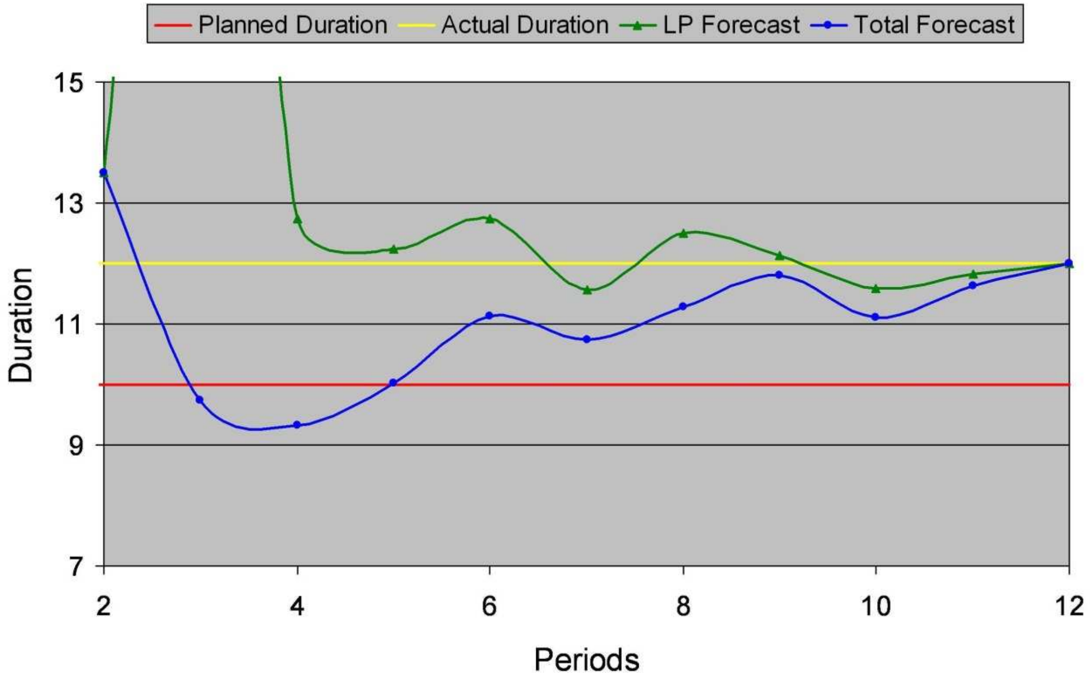
- ES-LP forecasts are hi-lighted with the lime color
- Observe ES-LP > ES-T …for every period
- CP is path 1-4-8-10, but is LP in only period #2

ES-LP versus ES-T Forecasts

Period	1	2	3	4	5	6	7	8	9	10	11	12
Longest Path		1.50	11.83	0.43	0.39	0.49	0.48	0.48	0.45	0.45	0.43	0.41
Total Project		1.50	1.91	1.54	1.66	1.53	1.49	1.41	1.32	1.28	1.22	1.16
				Omitted periods 2 & 3 in Std Dev calculations								

- Smaller standard deviation (σ) from actual duration of ES-LP forecasts indicate ES-LP is more reliable than is ES-T for this set of data
- Also observed is that the σ of the ES-LP forecast is more stable than are the values for the ES-T forecasts

ES-LP versus ES-T Forecasts



- Both ES-LP and ES-T forecasts converge to the actual duration
- ES-LP converges much faster with less variation

Longest Path Summary

- Results from the examination using notional data indicates ES-LP forecasting is promising
- ES-LP is more complex than is ES-T, but is much simpler with less effort than is combining ES-T with schedule risk analysis
- ES-LP forecasting can be automated …making its application transparent to the analyst
- The results seen with notional data invite more research to assess the viability of ES-LP

Advanced Methods Summary

Advanced Methods Summary

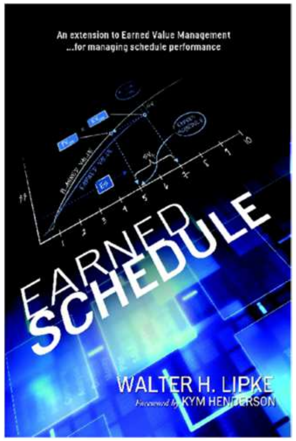
- ES accommodates performance baseline changes

  (Sorry …this was not presented due to time constraint)
- Detail analysis of schedule performance facilitated through Schedule Adherence …constraints/impediments
- SA provides capability to analyze rework and its impacts
- Method for circumstances of down time and stop work conditions
- Statistical Methods for planning and forecasting
- ES-LP improves forecasting for highly parallel schedules

Application Help

Available References

- Earned Schedule Website
  http://www.earnedschedule.com/
- PMI® *Practice Standard for Earned Value Management*, 2nd Edition
- *Earned Schedule* book (English, Japanese, Portuguese)
  - Print
  - ePub (Nook & iPad)
  - Kindle
  - PDF



Application Support

- Explore the Earned Schedule website
  - www.earnedschedule.com
  - Papers, Presentations, Calculators, Terminology
- Read two articles …*to begin*
  - "Schedule is Different"
  - "Further Developments in Earned Schedule"

Application Support

- Scan the Calculators …*experiment with them*
  - ES Calculator v1b & vs1b
  - Prediction Analysis Calculator
  - P-Factor Calculator
  - Statistical Planning Calculator
  - Statistical Forecasting Calculator
  - SA Index & Rework Calculator

Implementation Strategy

- Because you are already using EVM …*take the next step to ES*
- Try it on archived project data …*check the ES analysis against what occurred …gain confidence*
- Prototype ES on a few projects …*get comfortable with the analysis*
- Train others in ES and expand the application in the organization …*discuss with analysts and managers …work out the problems*
- Integrate into organization’s EVM application policy

EVM-ES Tools

- Initially, augment the EVM tool in use
  - ES calculators
  - Kym Henderson's set of spreadsheets
- Research the available tools - *request a trial period*
  - Project Flight Deck
    - MS Project add-on …inexpensive, yet includes advanced ES features
  - OR-AS
    - Sophisticated, research oriented, expensive
  - SuperTech – EV Engine
    - Basic EVM & ES …includes more financial analysis

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Review Questions

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 project constraints and impediments, and future rework.

- True
- False

Question #8

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

- Start Date + AC, EV, PV
- Start Date + AC, AT, PMB
- Start Date + PMB, EV, AT
- Start Date + PV, PMB, AT
- Start 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
- More pessimistic early forecast of final duration
- All of the above
- None of the above

Wrap-Up

Wrap Up

- ES 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 forecasting 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

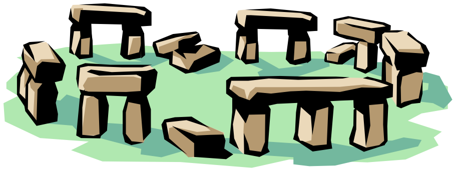
Wrap Up

- Schedule forecasting – much easier and possibly better than “bottom-up” schedule analysis
- Facilitates bridging EVM to schedule analysis
  - Identification of Constraints / Impediments and Rework
  - Calculation of Schedule Adherence
  - Forecast Cost of Rework
  - Creation of Longest Path Method

Leads to improved
Project Control & Performance

Conclusion

- Whatever can be done using EVM for Cost Analysis can also be done using Earned Schedule for Schedule Analysis …<u>and much more</u>
- Earned Schedule
  - A powerful new dimension to integrated Project Performance Management
  - A breakthrough in theory and application



the first scheduling system

Thank You for Attending!!

Best Wishes to All!