Earned Schedule

Master Class

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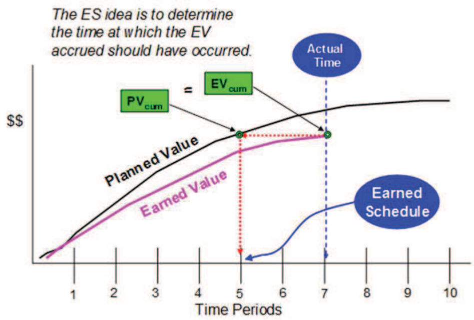


What Is Earned Schedule?

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 Methods

Earned Schedule - Overview

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

Earned Schedule - Overview

- Advanced Methods
- Re-Baseline Effects
- *Exercise – Forecast after Re-Baseline*
- Critical Path Application
- *Demonstration – Critical Path Analysis*
- Milestone Management
- *Demonstration – F-SV(t) & $TSPI_M$ Calculator*

Earned Schedule - Overview

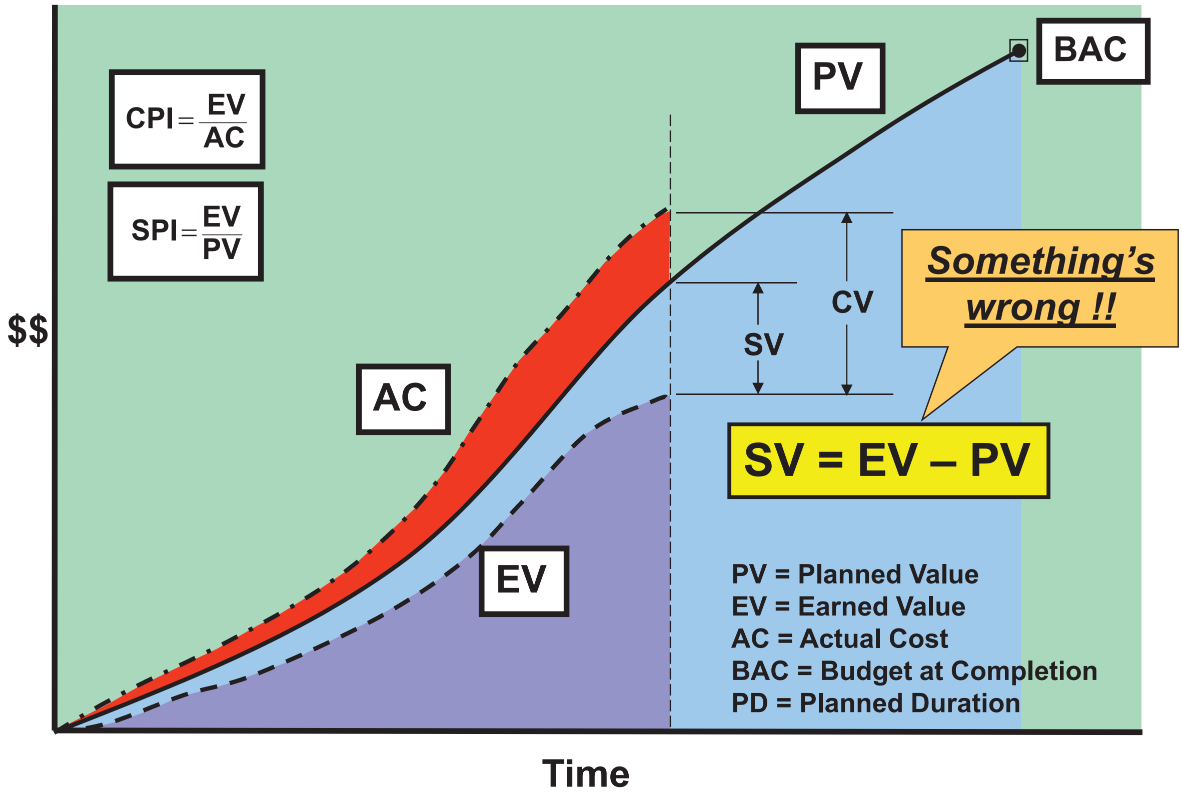
- Schedule Adherence
- Effective Earned Value
- *Demonstration – Schedule Adherence*
- SA Index & Rework Forecast
- *Demonstration – Rework Calculation*
- Statistical Methods
- *Demonstration – Statistical Planning*
- *Demonstration – Statistical Forecasting*
- *Demonstration – Recovery Probability*

Earned Schedule - Overview

- Small Projects
- *Demonstration – Small Projects*
- Longest Path Forecasting
- *Demonstration – Longest Path Forecasting*
- Advanced Methods Summary
- Application Help
- Review Questions
- Wrap Up

Introduction to Earned Schedule

EVM Schedule Indicators



EVM Schedule Indicators

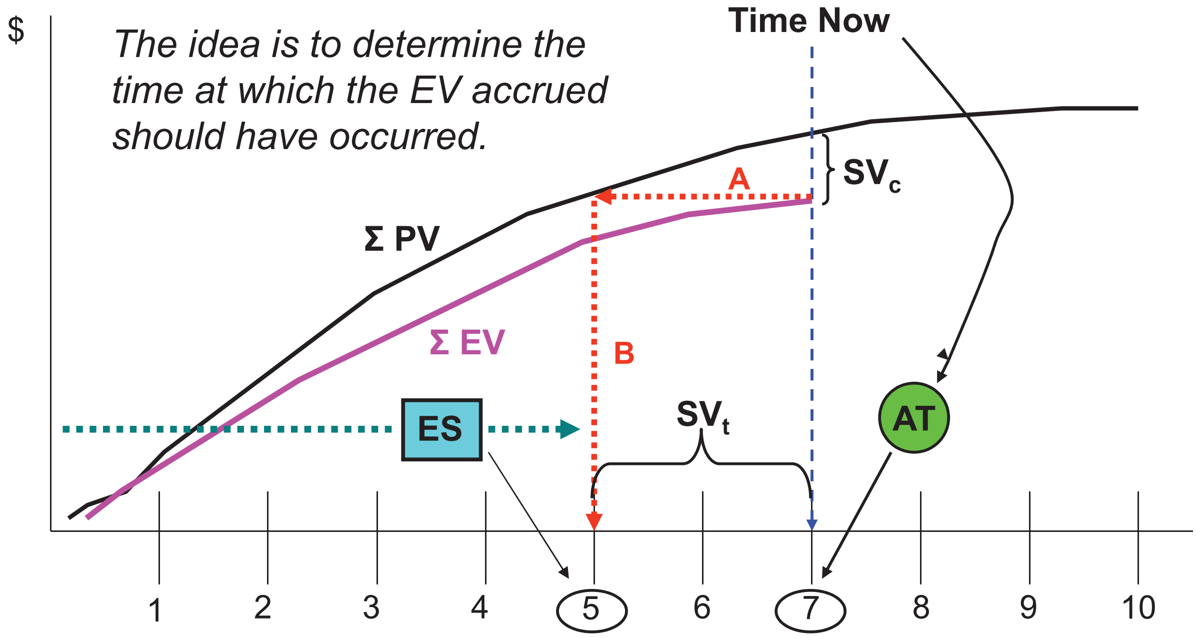
- SV & SPI behave erratically for projects behind schedule
  - SPI improves and concludes at 1.00 at end of project
  - SV improves and concludes at $0 variance at end of project
- Schedule indicators fail to accurately portray performance over the last third of the project

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 duration > 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:

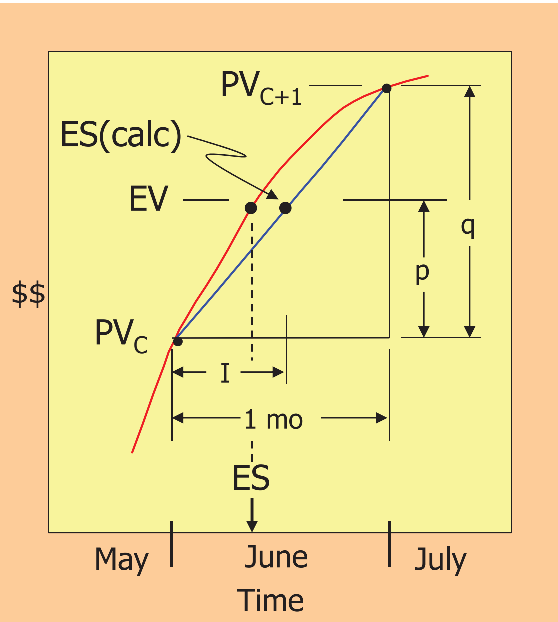
  Number of time increments (C) of PMB for which EV accrued equals or exceeds PV_n, plus the fraction (I) of the subsequent increment (C + 1)

- ES = C + I where:

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

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

Interpolation Calculation



$I / 1\ mo = p / q$

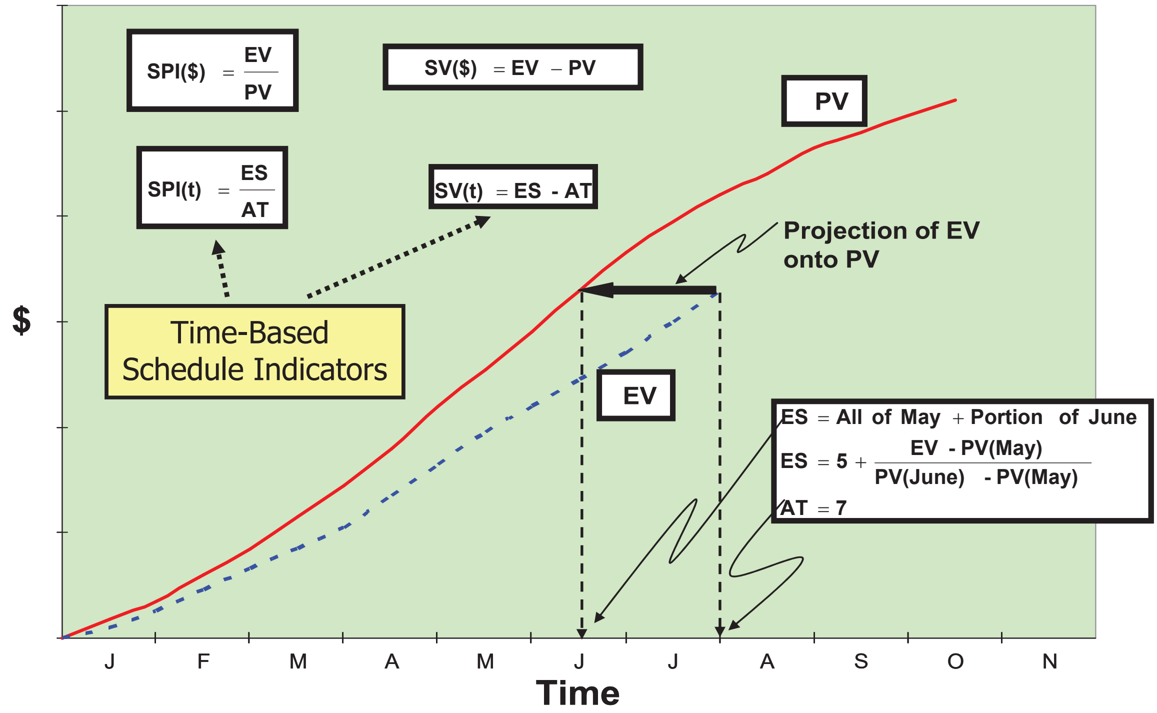
$I = (p / q) \bullet 1\ mo$

$p = EV - PV_C$

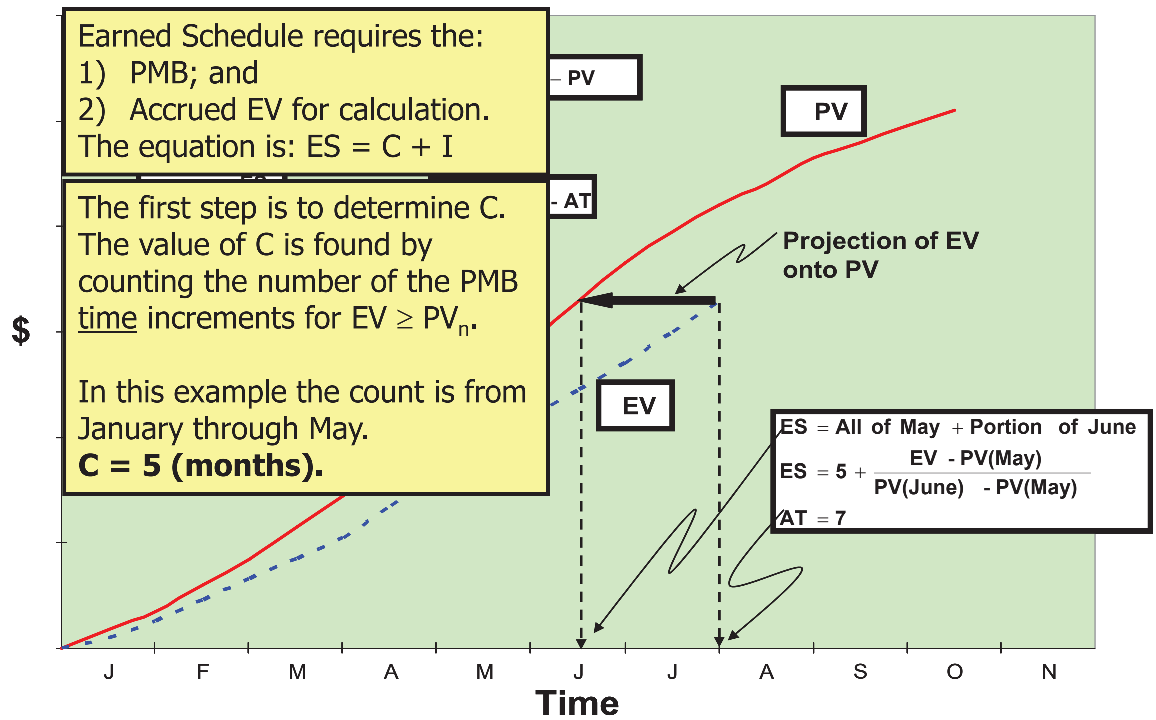
$q = PV_{C+1} - PV_C$

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

ES Computation Example



ES Computation Example

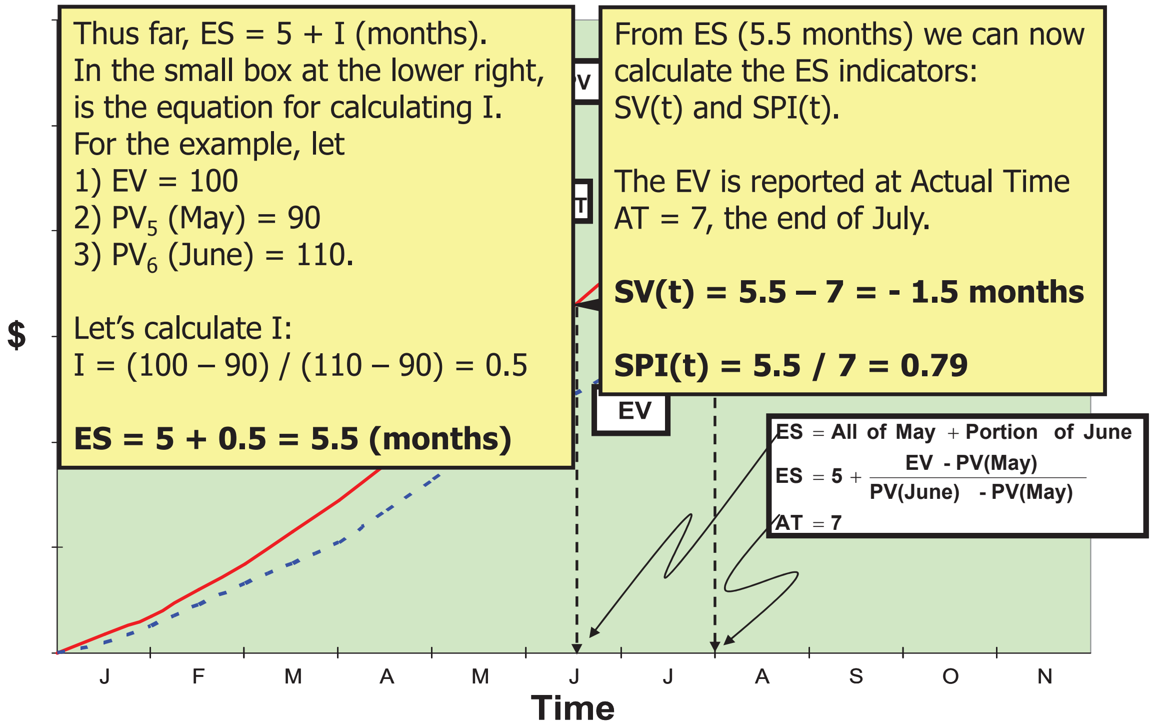


Earned Schedule requires the:
1) PMB; and
2) Accrued EV for calculation.
The equation is: ES = C + I

The first step is to determine C. The value of C is found by counting the number of the PMB time 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
- $ES_{period}(n) = ES_{cum}(n) – ES_{cum}(n-1) = \Delta ES_{cum}$
- $AT_{period}(n) = AT_{cum}(n) – AT_{cum}(n-1) = \Delta AT_{cum}$
  - 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

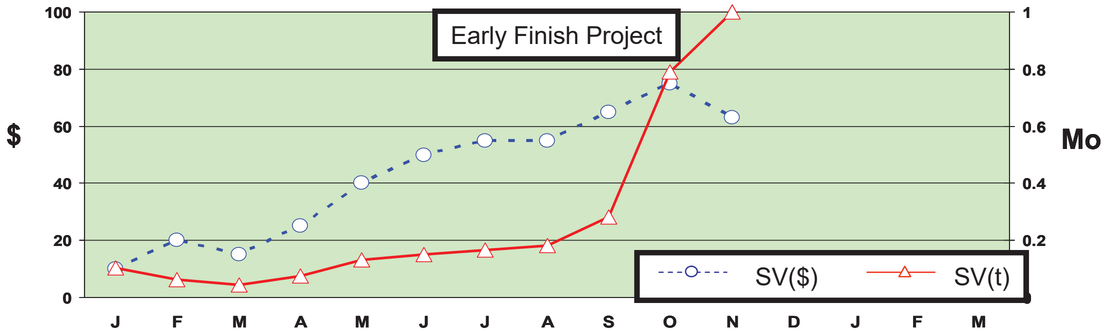
- What happens to the ES indicators, SV(t) & SPI(t), when the planned project duration (PD) is exceeded (PV = BAC)?

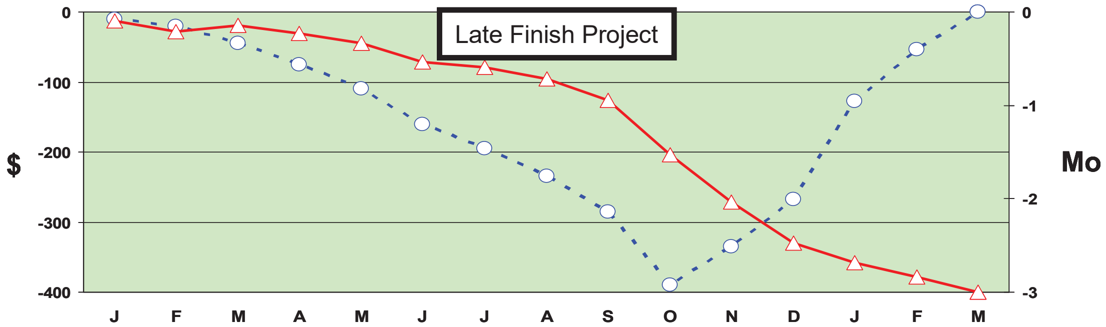
  They Still Work …Correctly!!

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

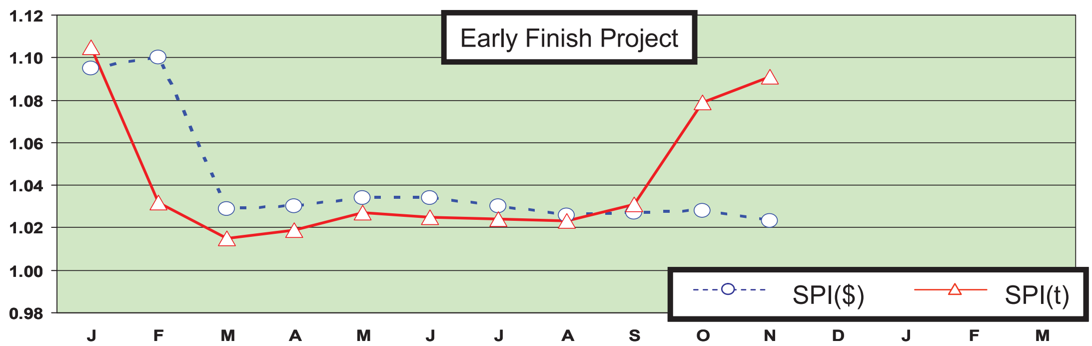
  Reliable Values from Start to Finish !!

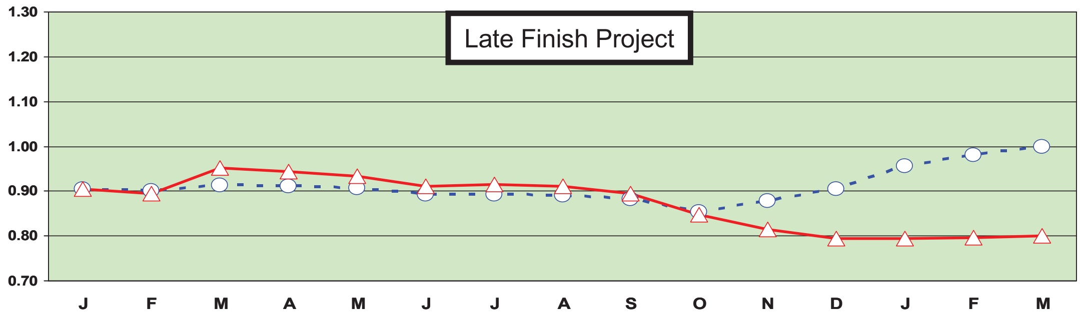
SV to SV(t) Comparison





SPI to SPI(t) Comparison





Earned Schedule Key Points

- ES indicators, SV(t) and SPI(t), behave in an analogous manner to the EVM Cost Indicators, CV and CPI
  - Not constrained by BAC calculation reference
  - Provide time-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 (or Desired) Duration
- Historically, “YES” when TSPI $\leq$ 1.10

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

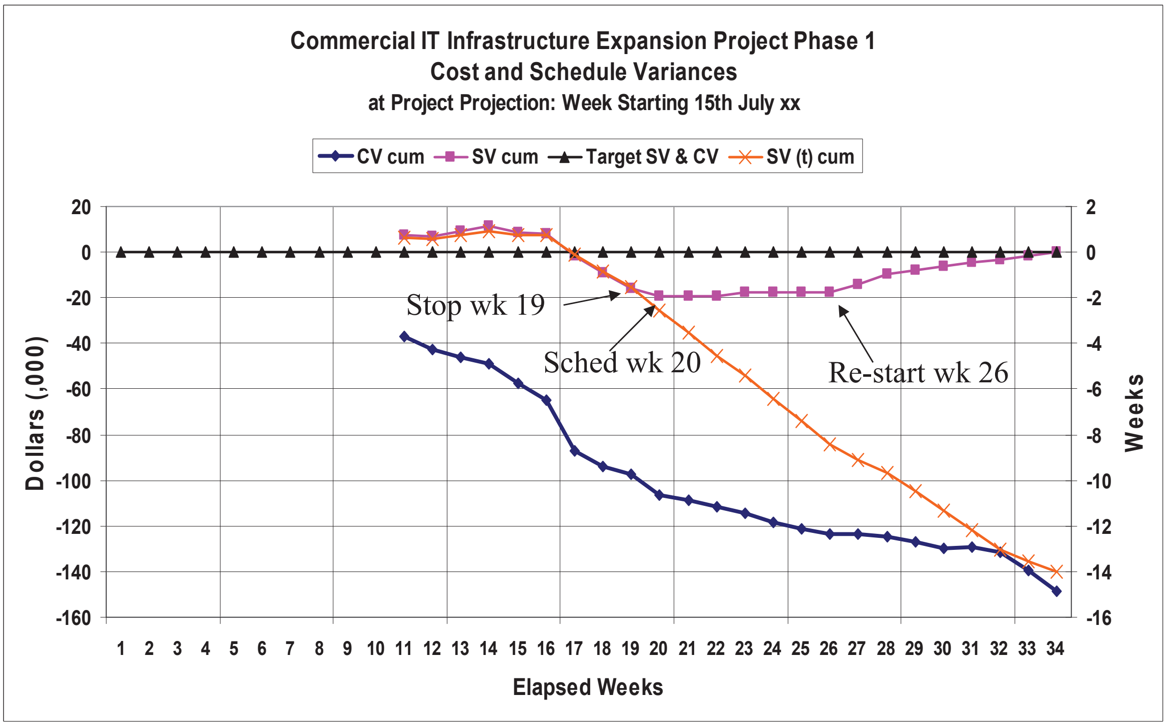
Metrics	Earned Schedule	ES_{cum}	ES = C + I number of periods (C), EV ≥ PV_C plus an incomplete portion (I)
	Actual Time	AT_{cum}	AT = number of periods executed
Indicators	Schedule Variance	SV(t)	SV(t) = ES – AT
		SV(t)%	SV(t)% = (ES – AT) / ES
	Schedule Performance Index	SPI(t)	SPI(t) = ES / AT
Predictor	To Complete Schedule Performance Index	TSPI	TSPI = (PD – ES) / (PD – AT)
			TSPI = (PD – ES) / (ED – AT)
Forecasts	Independent Estimate at Completion (time)	IEAC(t)	IEAC(t) = PD / SPI(t)
			IEAC(t) = AT + (PD – ES) / PF(t)
	Variance at Completion (time)	VAC(t)	VAC(t) = PD – IEAC(t) or ED

Verification of ES Method

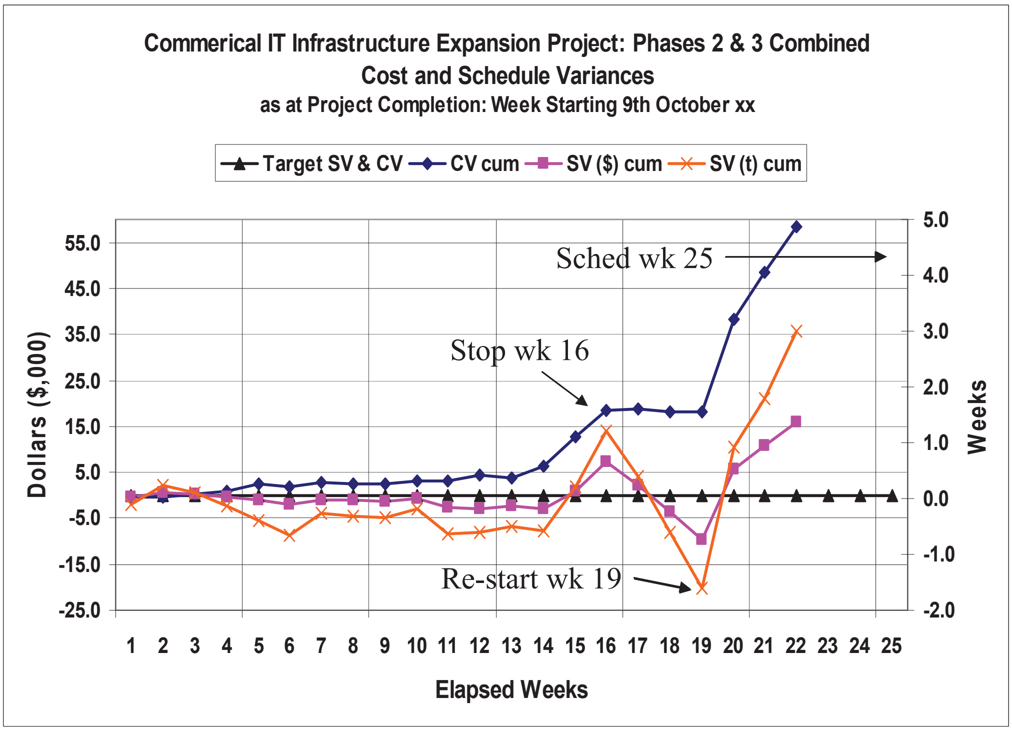
Application & Research

ES Applied to Real Project Data:

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



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



IEAC(t) Forecast Comparison

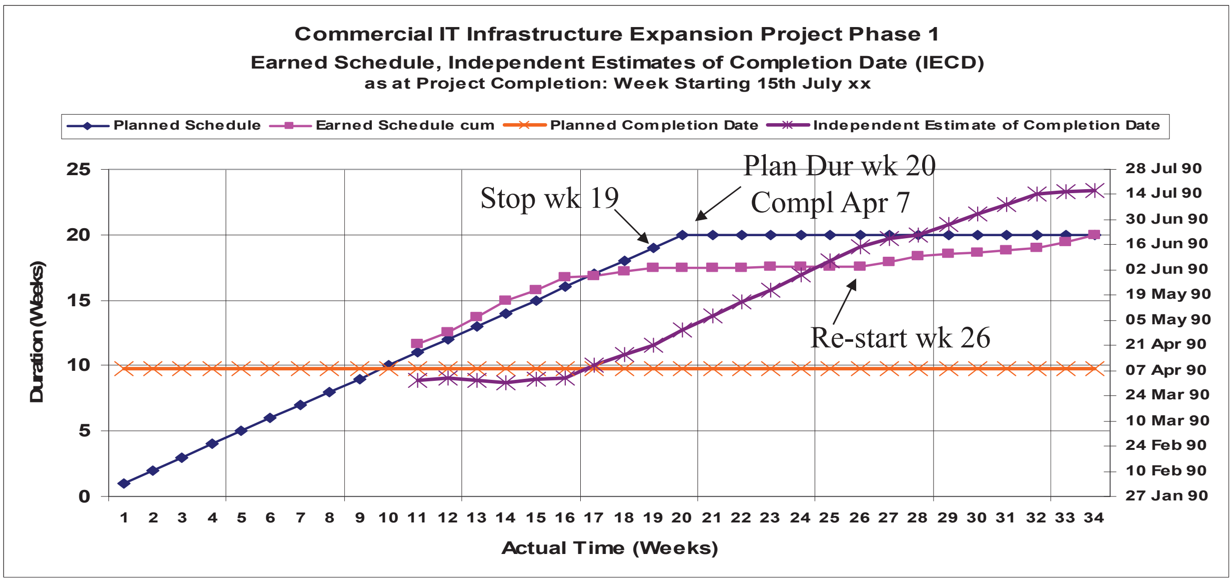
Early and Late Finish Project Examples

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

- Kym Henderson assessment
  - SPI(t) & SV(t) 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

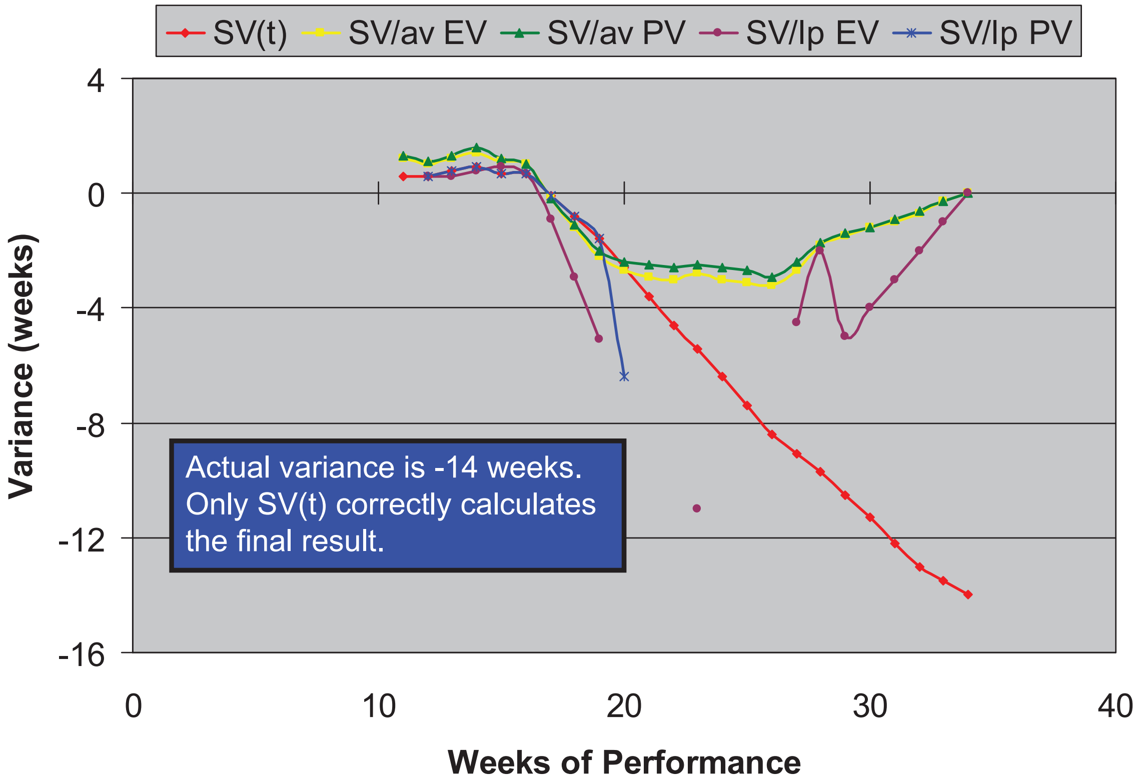
- Four EVM-based calculation methods in use
  - $SV_{avPV} = SV(\$) / (PV_{cum} / n)$
  - $SV_{avEV} = SV(\$) / (EV_{cum} / n)$

    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

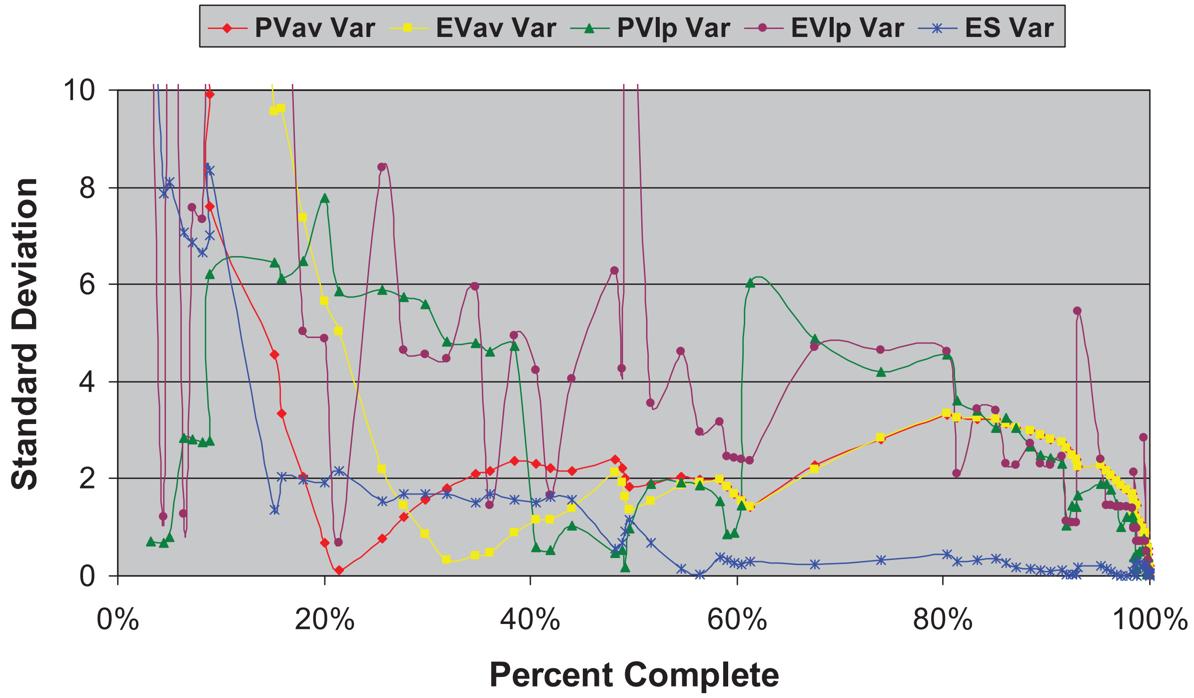
- Four Methods – all having same basic construct
  - Forecast Time = Current Duration + Time to Complete
  - Time to Complete = Work Remaining / (Work Rate)
- Fundamental equation
  - IEAC(t) = AT + (BAC – EV) / Work Rate
- Work Rates (Cost or Labor Hours per Unit of Time)
  - PV average = PV_{cum} /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

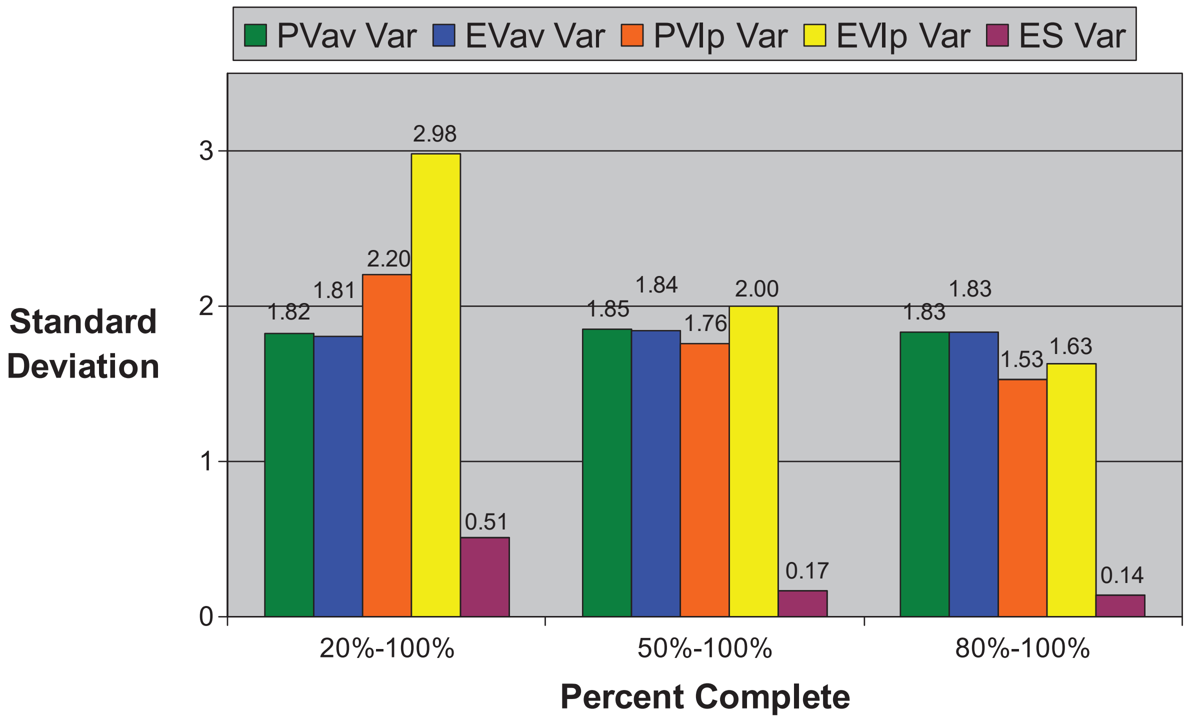
Time Forecasting Std Dev Comparisons

real data



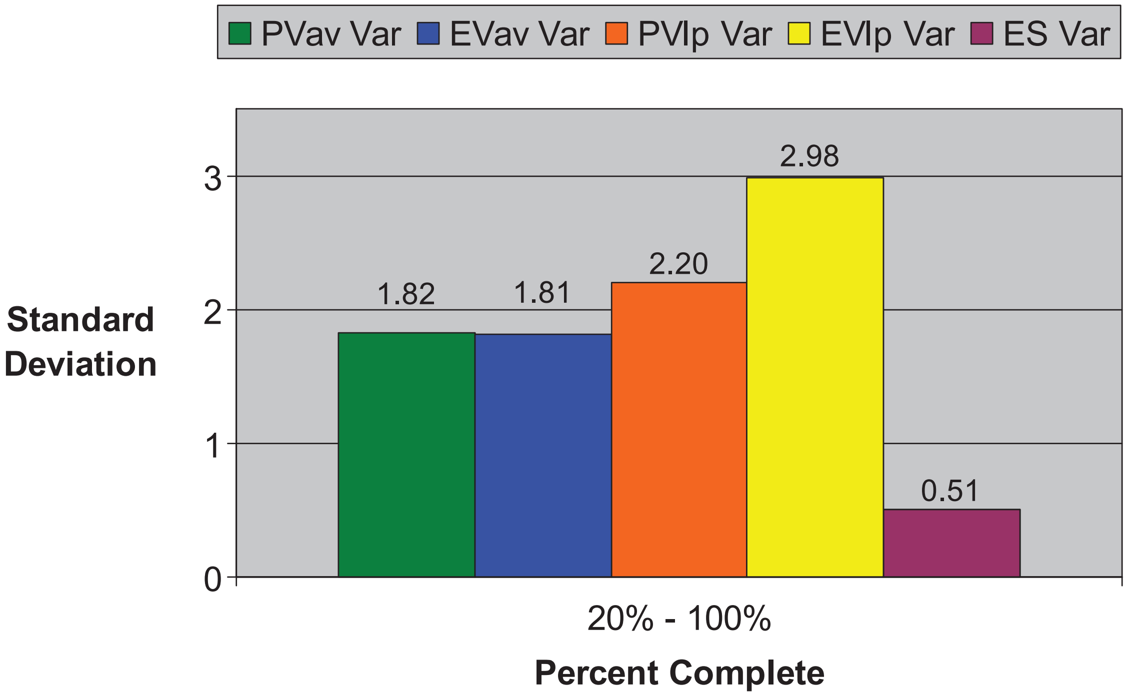
Comparison of Forecasting Accuracy

real data



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.

ES Forecasting Reliability

Forecasting Reliability

- Published research has cast some doubt on the reliability of ES forecasting
- Researcher made erroneous assumption and overlooked the fact that ES forecasting MUST converge to the actual duration at completion
- Sixteen projects of real data studied to determine convergence characteristic

Forecasting Reliability Evaluation

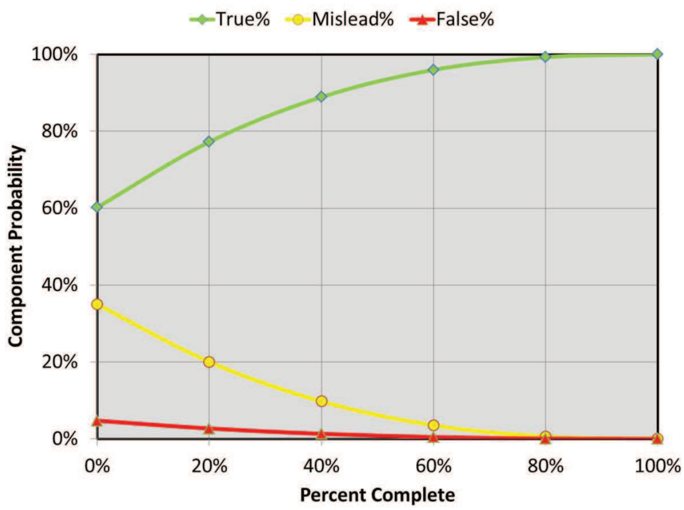
- Each project status point is classified to one of the nine scenarios using the chart …then grouped : TRUE, MISLEAD, FALSE

Outcome

Indicator	RD < PD	RD = PD	RD > PD
SPI(t) > 1	1 True	4 Mislead	7 False
SPI(t) = 1	2 Mislead	5 True	8 Mislead
SPI(t) < 1	3 False	6 Mislead	9 True

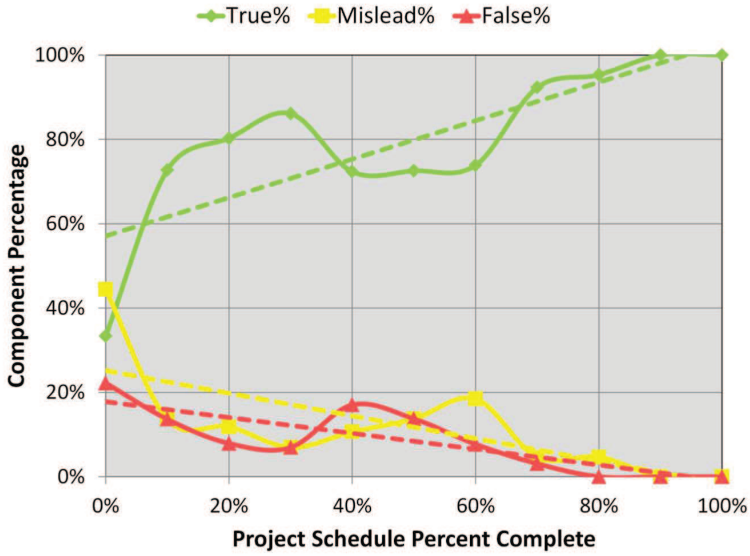
Forecasting Reliability Theory

- MISLEAD and FALSE scenarios resolve to consistency between SPI(t) and RD as the project progresses to conclusion …forecasts are predominately TRUE



Forecasting Reliability Results

- Linear fit of TRUE% indicates ES forecasting highly reliable …for 95% of project duration



Prediction Research

Prediction Research

- TCPI value of 1.10 has been used historically, but, until recently, has not been studied or verified
- Research indicates TSPI (and TCPI) values provide reliable and useful management information

TSPI Value	Predicted Outcome
≤ 1.00	Achievable
$> 1.00 \leq 1.10$	Recoverable
> 1.10	Not Achievable

Prediction Research - TSPI

- Recall …

  TSPI = (PD – ES) / (TD – AT)

  duration remaining ÷ time available
- Convert …divide numerator and denominator by PD

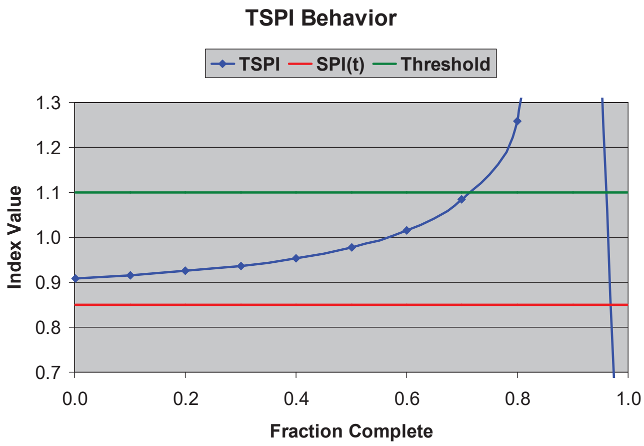
  TSPI = (1 – ES/PD) / (TD/PD – AT/PD • ES/ES)

  = (1 – ES%) / (SR – AT/ES • ES%)

  = (1 – ES%) / (SR – ES%/SPI(t))
- For any SPI(t) a graph of TSPI can be made for full range (0% ≤ ES% ≤ 100%)

Prediction Research - TSPI

- 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"

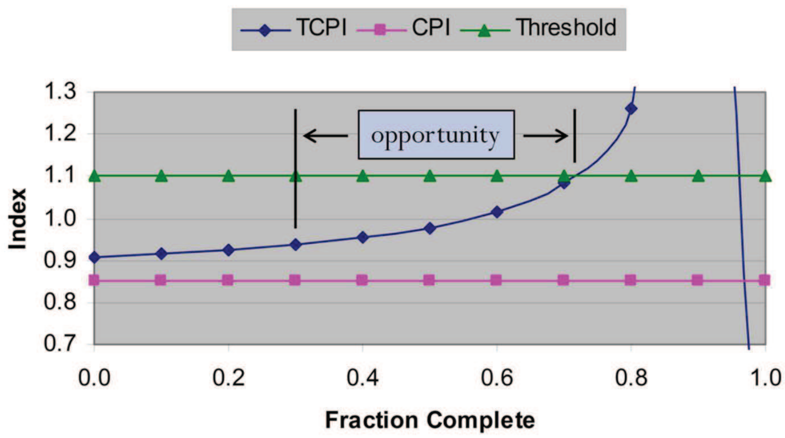


Prediction Research

- EVM data from twenty five projects was used to evaluate the validity of the TSPI and TCPI threshold value, 1.10
- Hypothesis tests were performed for each of the percentage levels (0, 5, 10, 15) for reserves
- The results from the examination of real data are confirmative …*it is unlikely the project can be recovered when the threshold value is exceeded (reserves included)*
  - An unexpected significant finding …*when the To Complete Index (TCPI or TSPI) does not exceed 1.10 after 20 percent complete, the project can be expected to meet its desired outcome (cost or duration)*

Prediction Research

- Significantly, this research affirmed that TCPI (and TSPI) could be used to determine the period of opportunity for project recovery



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 "PGCS ES Calculation Exercise" spreadsheet

ES Calculation Exercise

ES Calculation Exercise

ES Calculation Exercise

ES Calculation Answers

Exercise - ES Calculator & Forecasting Familiarity

Earned Schedule Calculator

ES Calculator v1b

Exercise – Prediction Familiarity

ES Prediction Calculator

TSPI Prediction Calculator

ES Usage & Propagation

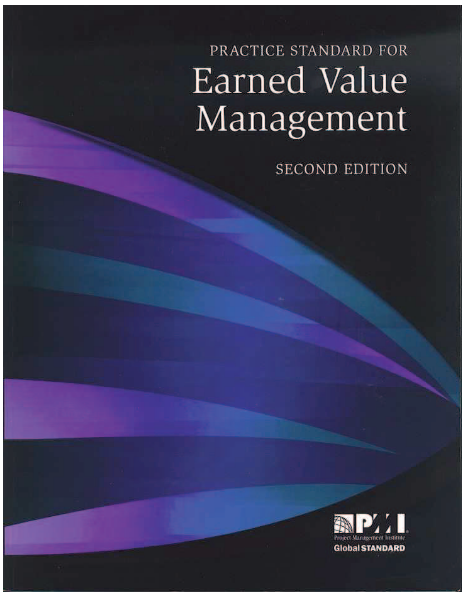
Application Expanding Globally

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	

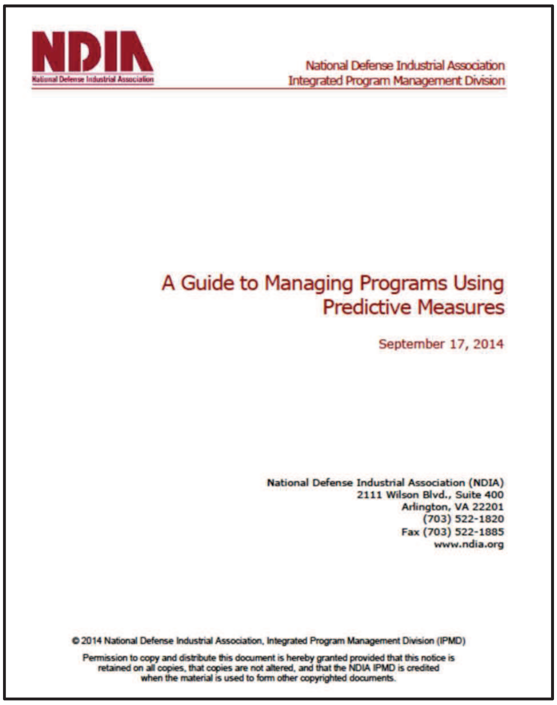
PMI Acknowledges ES

- *Practice Standard for EVM*, 2nd Edition (2011)
- *Project Management Body of Knowledge*, 6th Edition (2017)
- *Practice Standard for Scheduling*, 3rd Edition (in Draft)



NDIA Guides / ISO-EVM

- *A Guide to Managing Programs Using Predictive Measures* (2014)
- *Planning & Scheduling Excellence Guide* (2016)
- ISO standard 21508, *EVM in Project and Programme Management* (2018)


NDIA
National Defense Industrial Association

National Defense Industrial Association
Integrated Program Management Division

A Guide to Managing Programs Using
Predictive Measures

September 17, 2014

National Defense Industrial Association (NDIA)
2111 Wilson Blvd., Suite 400
Arlington, VA 22201
(703) 522-1820
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www.ndia.org

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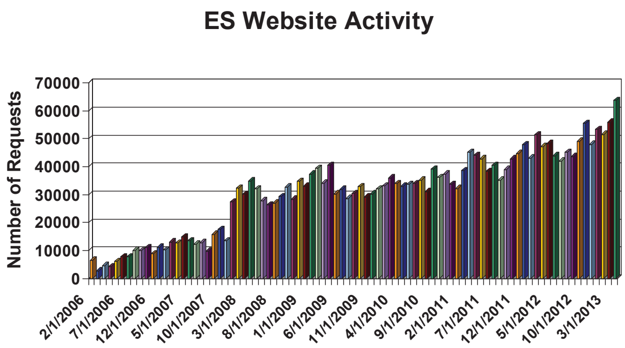
ES Website & YouTube Video

- Website established February 2006
- Contains *News, Papers, Presentations, ES Terminology, ES Calculators, Concept Description, Introduction Video*
- Identifies *Contacts, Analysis Tools & Training Sources* to assist with application
- The website activity has grown (>100K/mo)
- …as has the viewing frequency (≈ 4/day) of the YouTube video.



EVM/ES Training Sources

- Management Technologies
  - www.mgmt-technologies.com
- SM&A Project Management Training
  - https://www.smawins.com/seminars.aspx
- Project Management Training Institute
  - www.4pmti.com

EVM Analysis Tools with ES

- ***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, Longest* Path, and other advanced concepts
  - More information at: 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 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

Summary - Basic

- Completion Date forecasting – much easier and possibly better than "bottom-up" schedule analysis
- Application occurring in all types of projects
- Practice recognized by PMI: *EVM Practice Standard*, *PMBOK* and *Scheduling Practice Standard* (draft)
- Inclusion in NDIA Guides and ISO/EVM Standard
- Resource availability/propagation enhanced with ES website and Wikipedia
- Research indicates ES superior to other methods

Advanced Methods

Advanced Methods

- Re-Baseline Effects
- Critical Path Application
- Milestone Management
- Schedule Adherence
- Rework Forecast
- Statistical Methods
- Small Projects
- Longest Path Forecasting

Re-Baseline Effects

ES and Re-Baselining

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

Re-Baseline Effects

- Are indicators affected by a project re-baseline?
  - No when requirements are added or deleted
  - Yes when changes are made to the present estimates for task duration and effort
- When planned values for tasks are changed, essentially a new project is created
  - Measures (EV, AC, PV) prior to the re-baseline should not be co-mingled with those occurring after

Re-Baseline Effects

- How are indicators reported when the estimates are changed?
  - Fundamentally a new Project begins at the coordinates of the accrued Actual Cost and the Actual Date
  - Performance is closed out on the portion of the project completed
  - New cumulative indicators are begun for the revised portion of the project

Re-Baseline Effects

- For purpose of calculating indicators …
  - New Project Duration =
    Revised Completion Date – Actual Date
  - New Planned Duration =
    New Project Duration – Revised Schedule Reserve
  - New TAB = Revised TAB – Actual Cost
  - New BAC = New TAB – Revised MR
- The indicators are calculated using measures of EV, PV and AC for the portion of the project from the re-baseline to completion

Re-Baseline Effects

- For calculating forecasts after a re-baseline …
  - Cost:

    IEAC(total) = AC(re-plan) + IEAC(new)

    where IEAC(new) is the forecast for the portion of the project after the re-plan
  - Schedule:

    IEAC(t)(total) = AT(re-plan) + IEAC(t)(new)

    where IEAC(t)(new) is the forecast for the portion of the project after the re-plan

Exercise – Re-Baseline Forecast

Exercise – Re-Baseline Forecast

- Given: BAC = 2500, after the re-baseline
- Complete the data table and calculate the forecast of final cost
- If present performance continues, can the project complete within its budget?

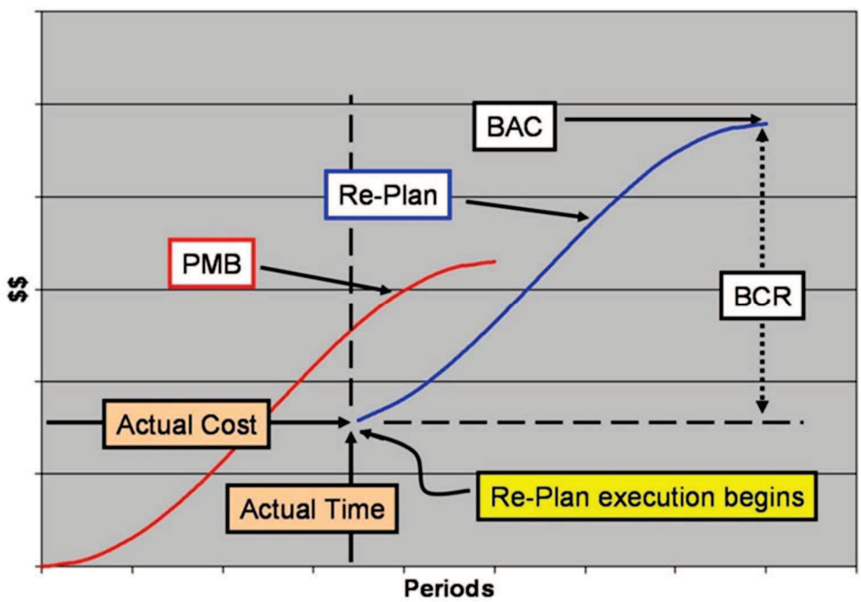
Use the Excel spreadsheet "PGCS Re-Baseline Forecast"

Period	ACmo	ACcum	EVmo	EVcum
1	35	35	40	40
2	50	85	45	85
3	85	170	75	160
4	100	270	90	250
5	115	385	100	350
6	110	495	85	435
7	105	600	75	510
8	115	715	60	570
9	110	825	85	655
10	100	925	95	750
***** Re-Baseline *****				
11	100		105	
12	115		105	
13	120		130	
14	105		115	

Re-Baseline Forecast

Re-Baseline
Forecast Exercise

Exercise – Re-Baseline Forecast



Note: Shift of PMB to Re-Baseline and BCR = BAC - AC

Exercise – Re-Baseline Forecast

Exercise
Re-Baseline Forecast

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 direct measure of CP performance …EV accrual can come from any task
- First method – compare IEAC(t) to the CP forecast
  - BAH & Henderson used this method – execution problems were identified earlier from the ES forecast
  - Although ES forecast 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

Demonstration – Critical Path Analysis

Demonstration – 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?

Demo – 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

Demo – 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

Milestone Management

Milestone Management

- Generally, large projects have milestones …to assess progress through evaluation of product characteristics
- EVM/ES normal application – current status, prediction, and forecast …does not address milestones
- Application to project milestone? …is it possible?

Milestone Management

- How can achievement of the milestone be assessed?
  - Identify tasks that make up milestone achievement
  - Create PMB for milestone, i.e. PMB_M
  - Thus …EV_M, PV_M …and ES_M
- Are indicators affected?
  - Yes, they represent the milestone and not the project
  - $SPI(t)_M$ & $SV(t)_M$ describe current performance for milestone
- $IEAC(t)_M$ & $TSPI_M$ are dependent upon the target duration …their formulas require modification

Milestone Management

- Modified forecasting and prediction formulas …substitute Milestone Duration (MD) for PD
  - $IEAC(t)_M = MD / SPI(t)_M$
  - $IEAC(t)_M = AT + (MD – ES_M) / PF(t)$
  - $TSPI_M = (MD – ES_M) / (MD \text{ or } ED_M – AT)$

    where ED_M = MD + planned slack
- Forecast schedule variance to the milestone
  - $F\text{-}SV(t) = MD – IEAC(t)_M$ *(use ED_M when slack > 0)*
  - Provides two items of information – variance and calendar time

Milestone Management

- Application to Milestone Control
  - Improvement from periods 1-7 to 8 -13
  - Milestone is 4 days after period 18 with 1 day slack
  - Current Period 13 – forecast minus 2 days, recovery possible over the next 5 periods

Period	1	2	3	4	5	6	7	8	9	10	11	12	13
F-SV(t)	-8	-45	-13	-16	-12	-4	-9	-5	1	1	0	-5	-2
$TSPI_M$	0.996	1.023	1.010	1.022	1.022	1.005	1.032	1.019	0.988	0.985	0.993	1.053	1.024

  - *ES Calculator – Milestone SV(t) Forecast* ….available from ES website

Milestone Management Summary

- EVM/ES does not provide direct management information concerning milestone achievement
- ES project forecasting & prediction formulas modified
- Forecast SV(t) & $TSPI_M$ useful for milestone control

Demonstration – F-SV(t) & $TSPI_M$ Calculator

Exercise – Milestone Management

- Become familiar with ES Calculator – Milestone SV(t) Forecast v1
  - Open the Excel file. Review the Instructions and the notes on the Example Data & Results (ED&R) sheet
  - View the Milestone Forecast sheet. The data entered corresponds to the results shown on the Analysis Table and Screenshot sheets.
  - Clear all data entries from Milestone Forecast sheet.
  - Load the example data from the ED&R sheet to the Milestone Forecast sheet.
  - Verify the computed results to the values on the ED&R sheet

Milestone SV(t) - Calculator

Milestone SV(t)
Forecast Calculator

Schedule Adherence

Schedule Adherence

- Recall the initiatives to improve project performance and quality over the last 30+ 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:

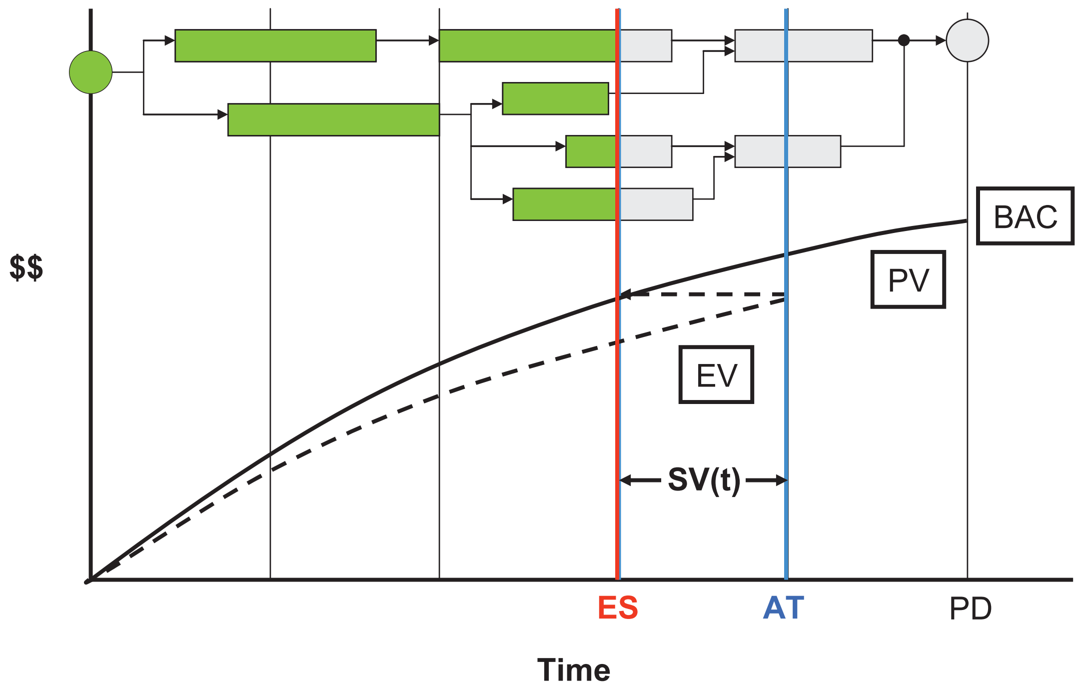
Did the accomplishment match exactly the expectation from the planned schedule?
- "Schedule Adherence" -

- 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

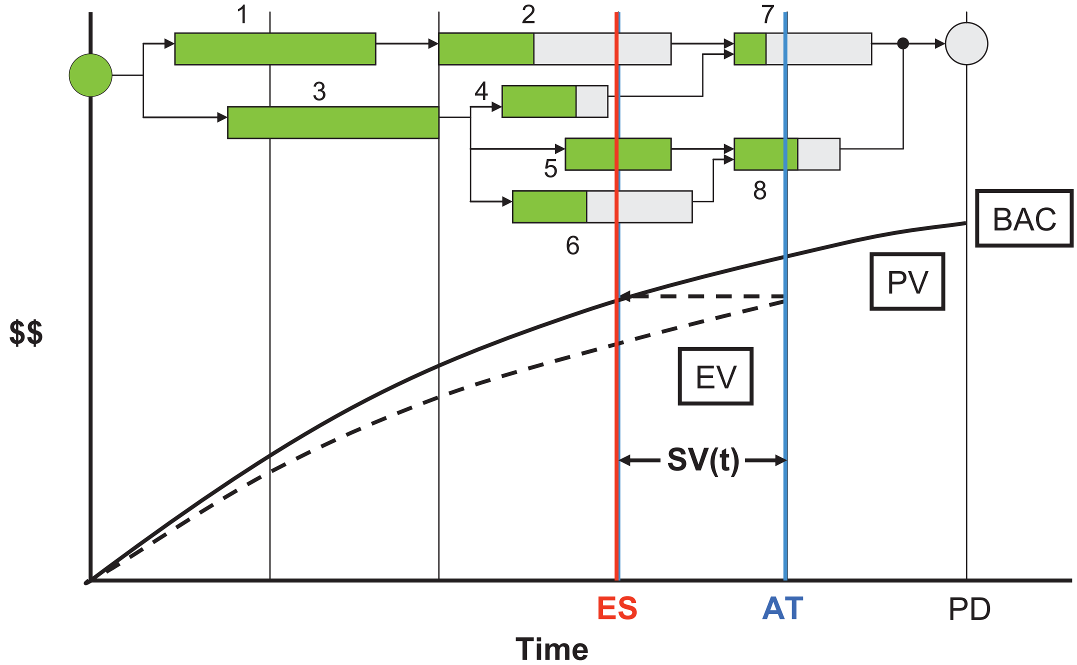


Measuring Schedule Adherence

- 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

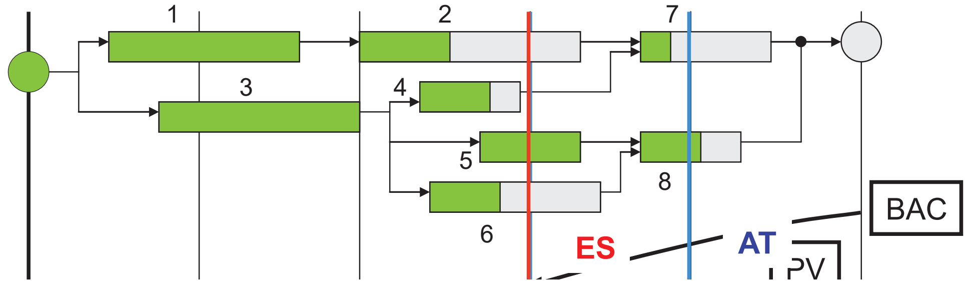
- When the value of P is much less than 1.0 the PM has a strong indication of an impediment, overload of a constraint, or poor process discipline
- When P has a value very close to 1.0, the PM can feel confident the schedule is being followed ….and that milestones and interim products are occurring in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

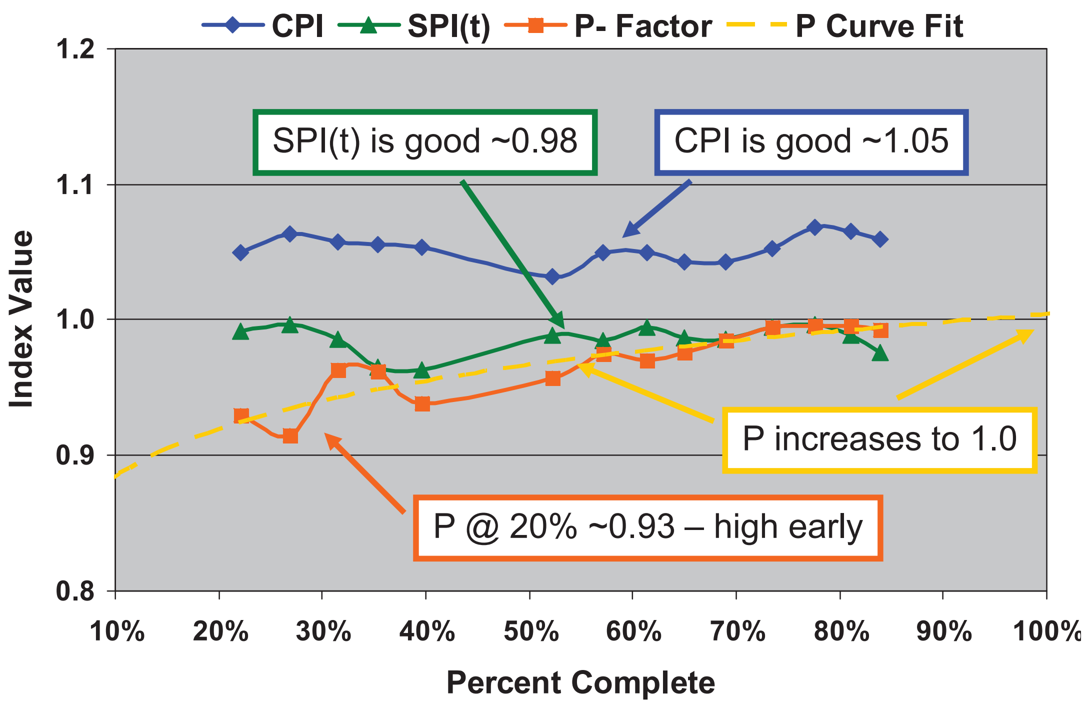
- From the value of P …~80 percent of the execution is in conformance with the schedule
- Presuming all of the claimed accomplishment not in agreement with the schedule requires rework, i.e. 7 units ….then:
  - ~18 percent of claimed EV requires rework
  - Without a large amount of MR, successful completion 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

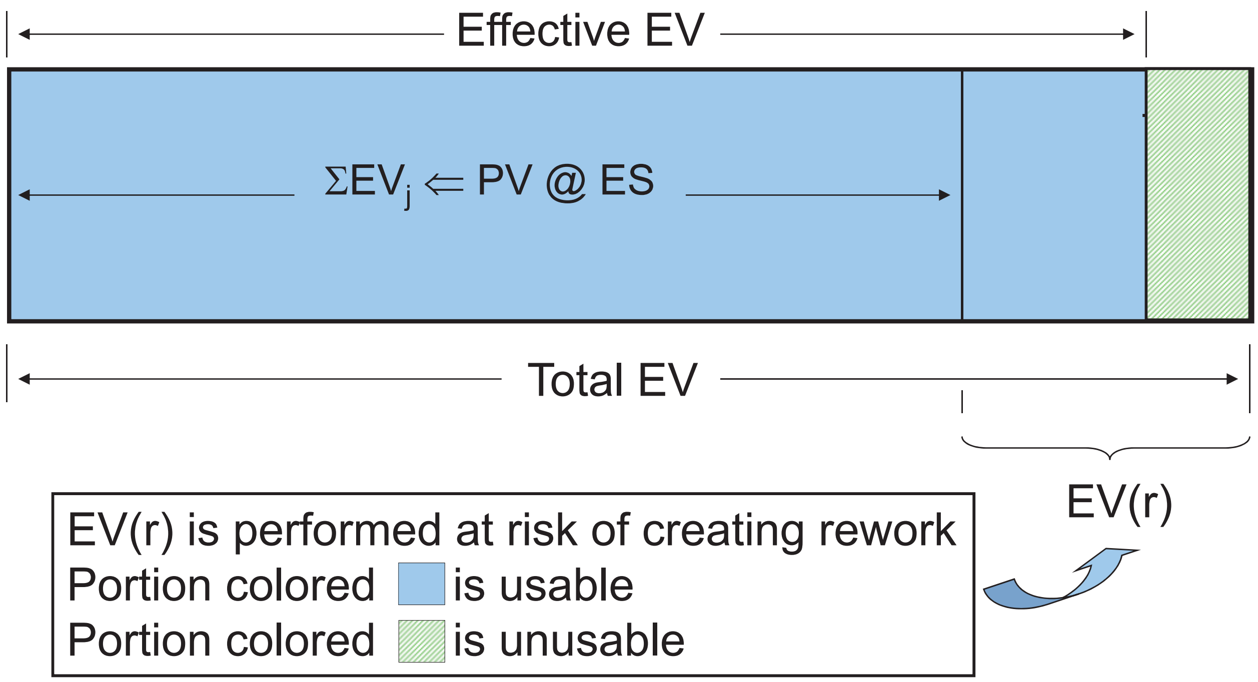
- Some EVM experts & practitioners believe that schedule analysis is possible only through detailed examination of the network schedule
- *Schedule Adherence* is a PM tool for process control not available from traditional analysis of the network schedule
- Use of the P-Factor measure is encouraged …a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

Effective Earned Value

Effective Earned Value

- From Schedule Adherence we know that not all of the EV claimed represents true progress …because some rework is expected
- Reducing the EV claimed by the rework defines "Effective Earned Value"
- The rework from out of sequence performance is calculable

Effective Earned Value

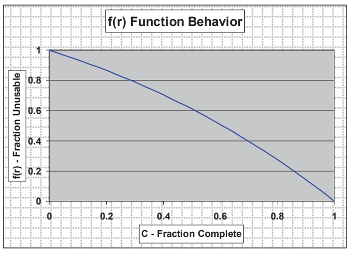


Effective Earned Value

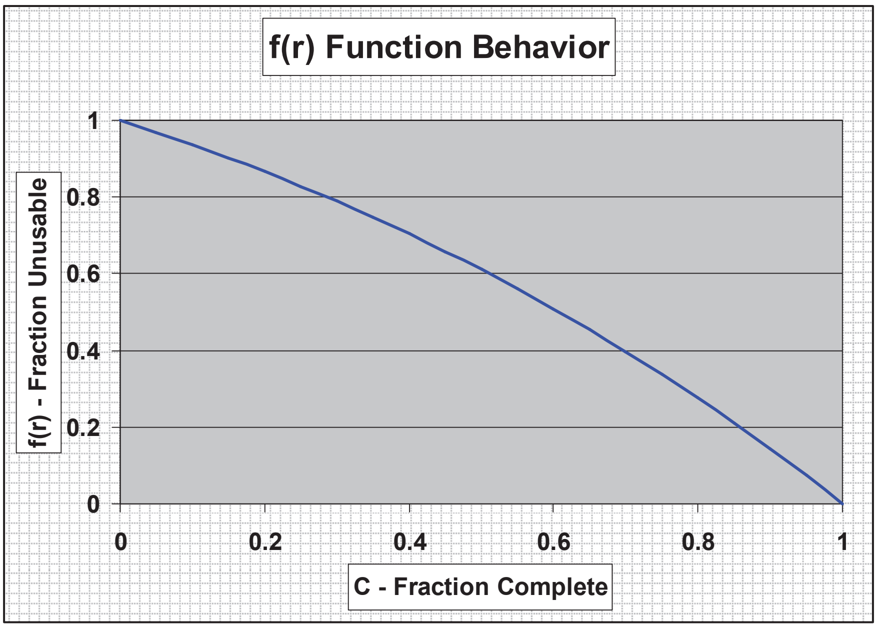
- Effective Earned Value, EV(e), is the blue portion in the previous slide …which has two parts
  - The portion of EV in alignment with PV @ ES
  - The portion of EV in misalignment that is usable
- Doing the algebra …

$$EV(e) = [1 – f(r) \times (1 – P)] \times EV$$

  - f(r) is the unusable fraction of the misaligned EV
  - f(r) varies with fraction complete (C)
    - f(r) = 1 @ C = 0.0
    - f(r) = 0 @ C = 1.0



Effective Earned Value

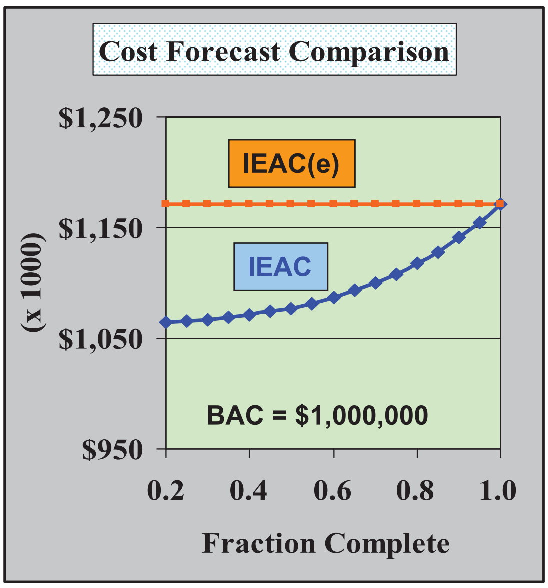


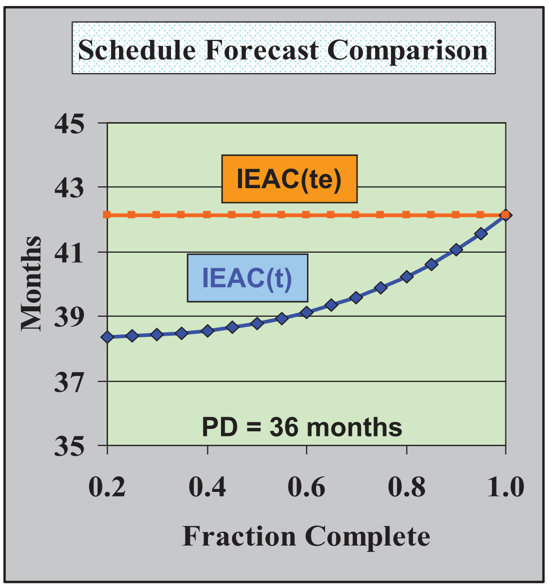
Effective Earned Value

- Effective ES is computed using EV(e) …*i.e., ES(e)*
- Effective EV and ES indicators/predictors/forecast are …

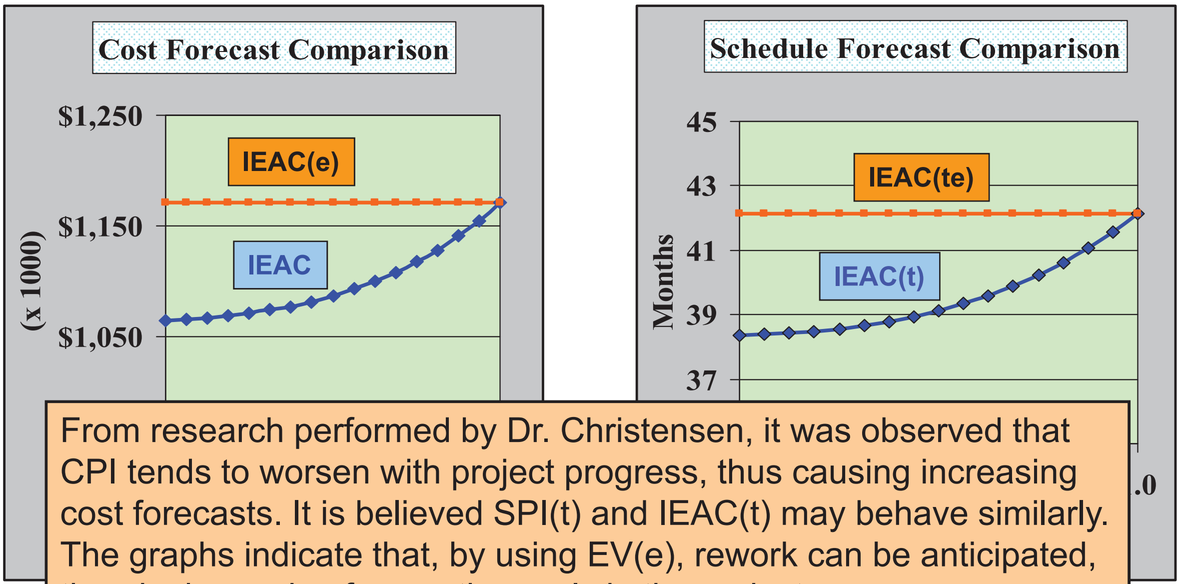
	Cost	Schedule
Indicators	CV(e) = EV(e) - AC	SV(te) = ES(e) - AT
	CPI(e) = EV(e) / AC	SPI(te) = ES(e) / AT
Predictors	TCPI(e) = [BAC – EV(e)] / [BAC – AC]	TSPI(e) = [PD – ES(e)] / [PD – AT]
	TCPI(e) = [BAC – EV(e)] / [EAC – AC]	TSPI(e) = [PD – ES(e)] / [ED – AT]
Forecast	IEAC(e) = BAC / CPI(e)	IEAC(te) = PD / SPI(te)

Theoretical Forecasts



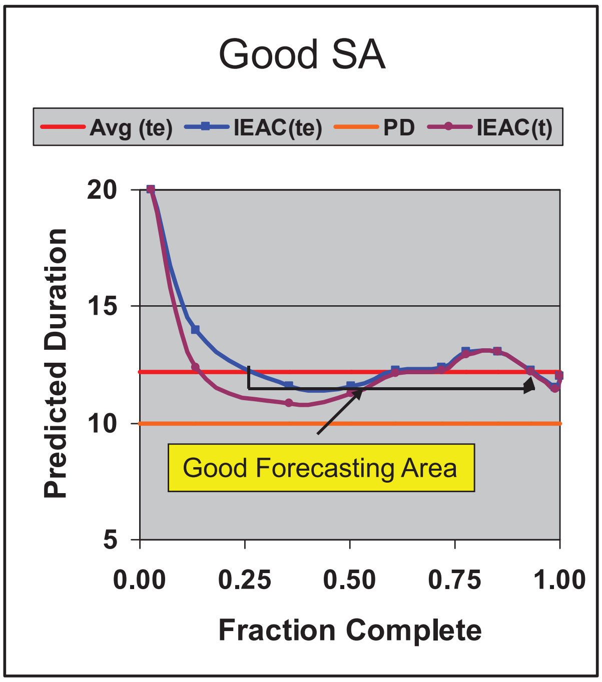


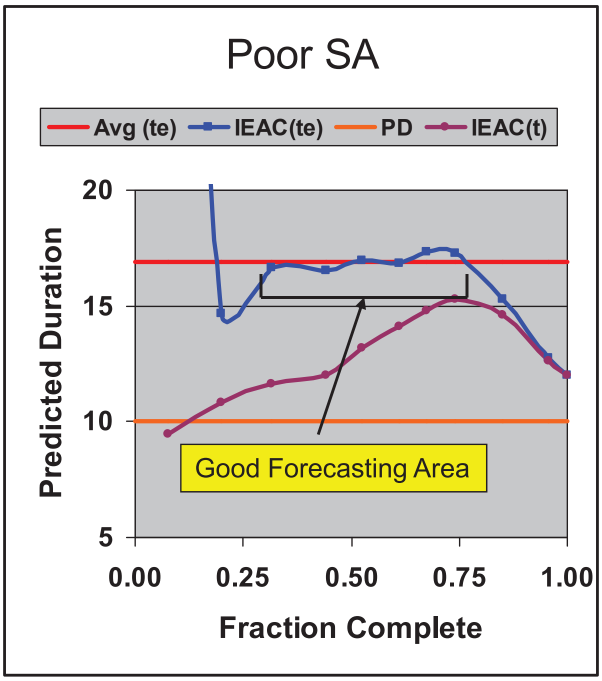
Theoretical Forecasts



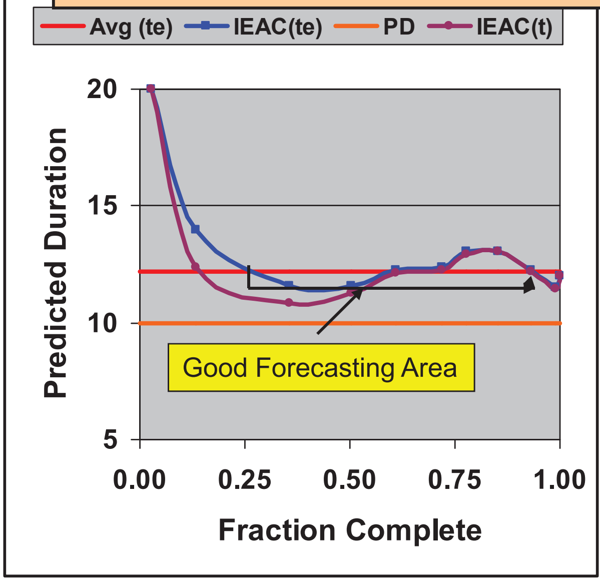
From research performed by Dr. Christensen, it was observed that CPI tends to worsen with project progress, thus causing increasing cost forecasts. It is believed SPI(t) and IEAC(t) may behave similarly. The graphs indicate that, by using EV(e), rework can be anticipated, thereby improving forecasting early in the project.

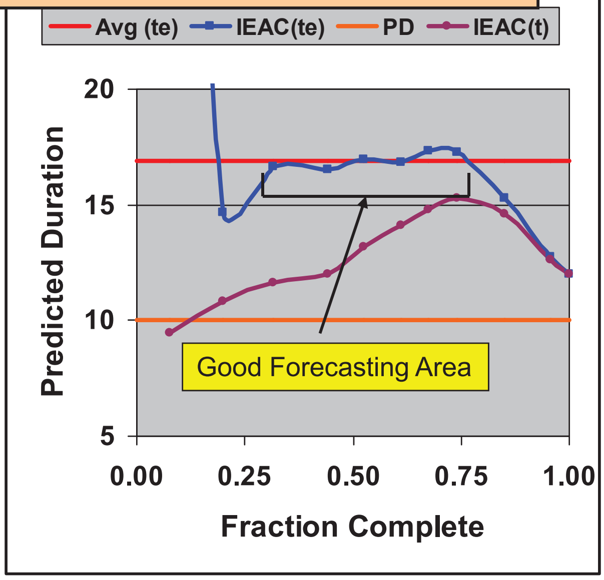
Duration Forecasts (notional data)



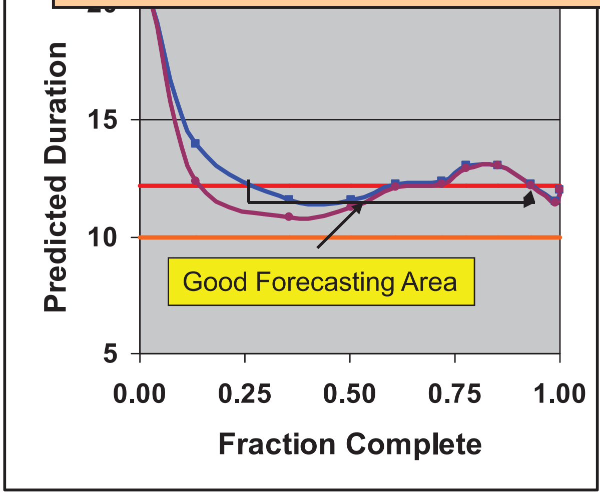


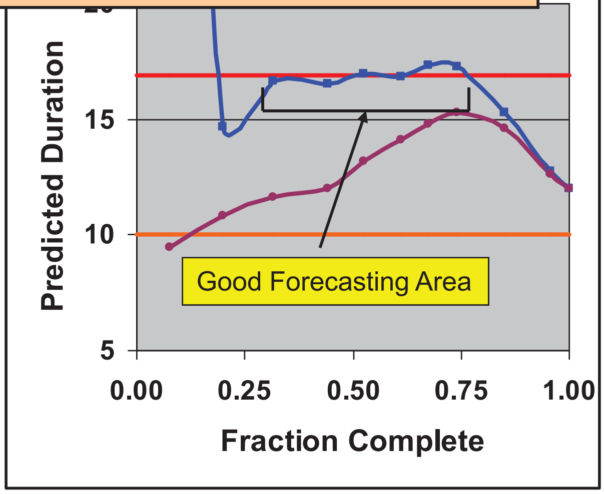
These graphs were created with notional data. The graph on the left shows the behavior of IEAC(t) and IEAC(te) when schedule adherence is good. As can be seen beginning at 0.25 until ~0.60 complete, IEAC(te) provides a better forecast. Thereafter the two forecasts are nearly identical.





The graph on the right shows the effect when schedule adherence during project execution is very poor. For the data set, completion was confined to be identical to the example in the left graph. Thus, the forecasting from 0.75 to completion is not representative in comparing IEAC(t) and IEAC(te). In the portion labeled "Good Forecasting Area," IEAC(t) is observed to continually worsen. However, the IEAC(te) forecast over the range shows very consistent forecast values …displaying the value of EV(e).





Approximate EV(e)

- Circumstances may preclude the ability or necessity for the analysis to compute P-Factor values
  - Schedule information is unavailable
  - Time – a "quick and dirty" result is needed

Is EV(e) analysis possible?

How?

Approximate EV(e)

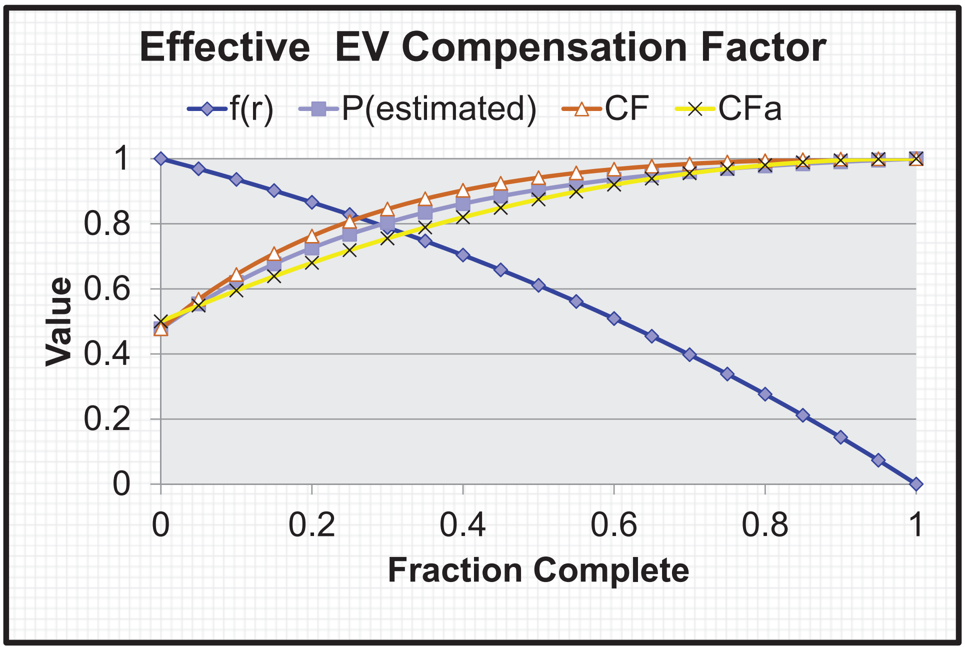
- Compensating function in equation

$$EV(e) = [\overbrace{1 - f(r) \times (1 - P)}] \times EV$$

may be approximated as $[1 - 0.5 \times (1 - C)^2]$

- When approximation is used …
  - P-Factor analysis is not necessary for calculation
  - Recommended for use when fraction complete < 0.50
  - Understand it is an approximation …generally more pessimistic

Approximate EV(e)



Summary: Effective Earned Value

- Lack of adherence to the schedule causes EV to misrepresent project progress
- Effective EV calculable from P, f(r), and EV accrued
- Approximation methods available …when appropriate
- EV(e) analysis most useful during early portion of project execution and when performance suffers from poor process discipline

Demonstration – Schedule Adherence

Exercise – Schedule Adherence

- Familiarity with P-Factor Calculator spreadsheet
  1) Enter Task Identifier and PV data from S-P Project sheet into Task PV@PT sheet
  2) Use dates already entered to Task PV@PT to identify planned start and completion dates. Enter those to appropriate cells beneath Start Dt (plan) and Compl Dt (plan). Enter total task PV for each task. Check red Data Status for “Data OK.” If “Entry Fault” appears, review entries and correct problem.
  3) On Data & P-Factor sheet enter the following:
     - Negotiated Completion Date: 10/31/2013
     - Project Reference Date: 1/1/2010
     - Budget at Completion: 200
     - Total Allocated Budget: 220

Exercise – Schedule Adherence

- Familiarity with P-Factor Calculator spreadsheet
  4) Note the computed results for
     - Planned Start Date / Planned Completion Date
     - Planned Duration / Planned Periods / Negotiated Duration
  5) From S-P Project sheet enter EV for first period of performance to Task EV@AT sheet. Scroll down to row 203 and observe that EV accrued is totaled for period 1.
  6) On the Data & P-Factor sheet enter the period number and the EV total to the cells to the right of Actual Time and Earned Value cum Reported
  7) Note the computed result for the P-Factor. At the right side of the sheet observe the AC & P-Factor Table. Enter AC accrued (none for this exercise) and paste P-Factor result to the table

Exercise – Schedule Adherence

- Familiarity with P-Factor Calculator spreadsheet

  8) Inspect Mgmt Review, IEAC Calc and P-Calc sheets
     - Mgmt Review: Observe the Flag problems for Tasks 1 & 2
     - IEAC Calc: Note that IEAC(te) > IEAC(t)
     - P-Calc: Inspect the data sheet
  9) Repeat process for entering the next few periods of EV. Correct any data entry errors and observe the computed results. Make the subsequent data entries to the AC & P-Factor Table and inspect the various worksheets.
  10) Note as the project approaches completion the P-Factor value increases and concludes at 1.00 when project finishes.

The P-Factor Calculator is a complex spreadsheet

Exercise – Schedule Adherence

Results for Serial-Parallel Data

Data & P-Factor Result

EV reported = EV recorded	Yes EVrep-EVcalc	Check of accuracy of data entry to the Task EV @ AT sheet. If "No," review data entry.
P-Factor	1.000000	Consult P-Calc sheet when error appears. Generally, a data entry error to the Task EV @ AT sheet is the problem.
Planned Start Date	1/1/2010	Date obtained from Task PV @ AT sheet.
Planned Completion Date	8/31/2013	Date obtained from Task PV @ AT sheet
Negotiated Completion Date	10/31/2013	Enter negotiated completion date.
Project Reference Date	1/1/2010	Enter start date of 1st full month of performance, when the first observation includes a partial month plus the first full month. Otherwise, enter planned start date. For weekly performance enter planned start date.
Planned Duration	44	Computed from Start & Completion entries
Planned Periods	44	Computed from Reference and Completion entries
Negotiated Duration	46.00	Computed project duration from negotiated completion date and planned start date
Earned Schedule @ AT	44.00	Computed ES value corresponding to AT. ES is computed using the V1 calculator.
Actual Time	20	Enter the number of the status period
Earned Value cum Reported	200	Enter cumulative value for EV reported in status report
Budget at Completion	200	Enter Budget at Completion
Total Allocated Budget	220	Enter the Total Allocated Budget (TAB = BAC + Management Reserve) *(Entry is optional)*
Percent Rework	x	When the percent rework algorithm is to be used, enter a non-numeric ("x"). Otherwise, enter decimal value representing rework percentage for tasks performed early with respect to the plan (e.g., 0.50 - meaning 50%)

Actual Cost & P-Factor Recording

Scroll right on this sheet to find the **AC & P-Factor Table**. As actual cost and P-Factor values are known record them in the table corresponding to the appropriate reporting period (AT). The AC value is simply entered. The P-Factor is copied and then pasted (special - values) to the cell beneath the P-Factor heading corresponding to the number in the AT column equal to the AT value displayed. The numbers entered facilitate the calculations performed in the **IEAC Calc** sheet.

AC & P-Factor Table

AT & P-Factor Displayed

AT = 20 | **P-Factor = 1.000000**

AT	AC	P-Factor
1		0.62500
2		0.71429
3		0.73529
4		0.74468
5		0.75000
6		0.73529
7		0.63953
8		0.60606
9		0.68750
10		0.76000
11		0.76087
12		0.82667
13		0.89506
14		0.94186
15		0.97222
16		1.00000
17		1.00000
18		1.00000
19		1.00000
20		1.00000
21		
22		
23		
24		
25		
26		
27		
28		

P-Factor Calculator

P-Factor Calculator

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

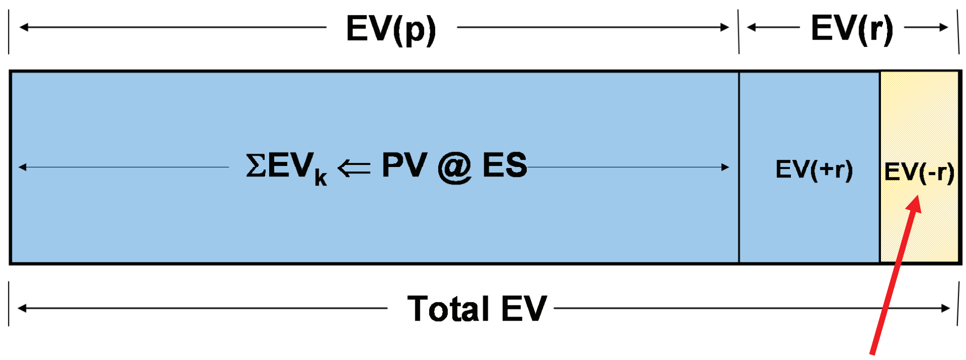
- Fundamental relationships:
  - EV accrued = ΣEV_j @ AT = ΣPV_k @ ES
  - EV earned in concordance with the schedule:

    EV(p) = ΣEV_k @ AT = P × 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) × 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):

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

  - 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
    - Rework fraction decreases as EV increases
    - Rate of f(r) decrease becomes larger as EV ⇒ 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

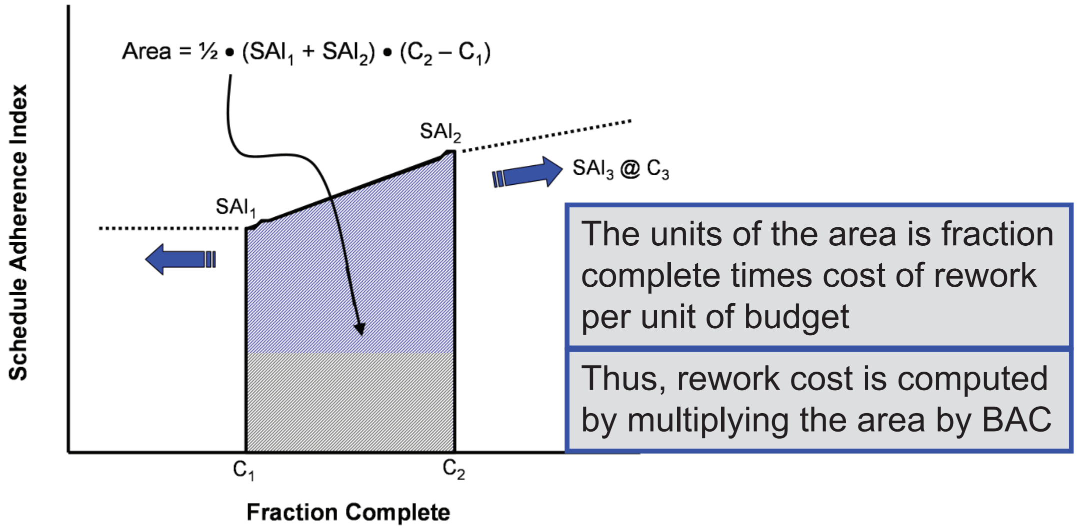
- R can be transformed to a useful indicator by dividing by the work remaining (BAC – EV):

  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 ⇒ SA worsening
  - SAI decreasing with EV ⇒ SA improving

Computation Methods

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



Computation Methods

- To obtain the rework cost for period n:

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

  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:

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

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

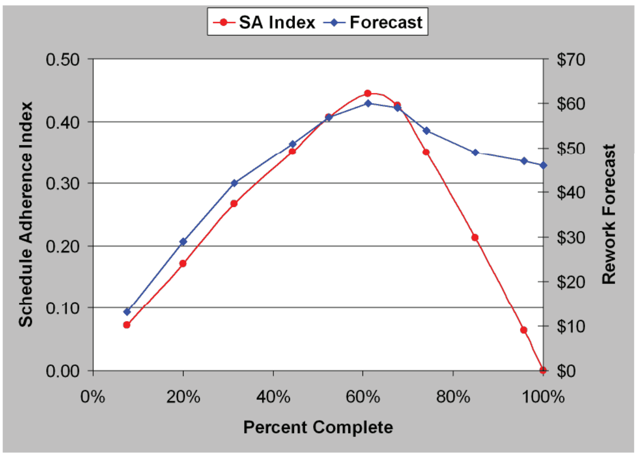
Notional Data Example

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

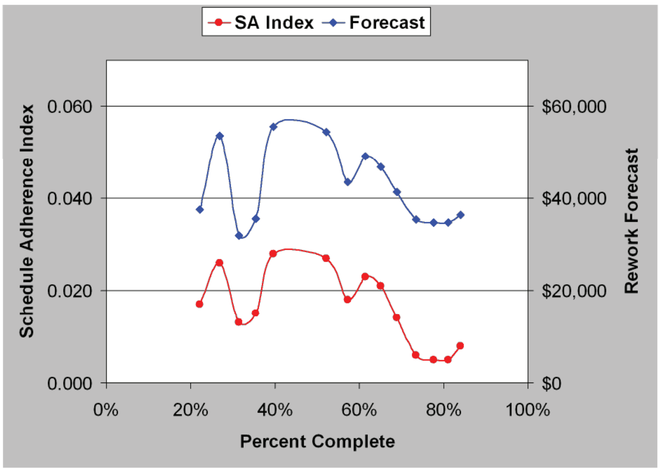
Status Point	1	2	3	4	5
Percent Complete	22.1%	26.9%	31.5%	35.4%	39.6%
SA Index	0.017	0.026	0.013	0.015	0.028
Rework Forecast	$37,483	$53,697	$31,945	$35,577	$55,671
Status Point	6	7	8	9	10
Percent Complete	52.2%	57.2%	61.4%	65.0%	69.0%
SA Index	0.027	0.018	0.023	0.021	0.014
Rework Forecast	$54,401	$43,519	$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.

Demonstration – Rework Calculator

Exercise – Rework Calculation

- Familiarity with the SA Index & Rework Calculator
  1) Open the Excel file and click on SAI & Rework Calculation sheet. Note that the entry cell values for BAC and the Measures, EV and P, are filled with #N/A (refer to Instruction).
  2) Click on the Example Data sheet. Copy and paste values from Trial Data 1 to BAC and Measures, EV and P, on the SAI & Rework Calculation sheet.
  3) Enter the EV and P data for period 1 and check the graph sheets. Then proceed with entering EV and P values for several periods at a time, while observing the graphs.
  4) Note the following – a) at completion, SAI = 0.0; b) Rework Forecast converges to its final value; c) Rework accrual < EV(r)

SA Index & Rework Calculator

SA Index &
Rework

Statistical Methods - Planning

Statistical Planning for Risk

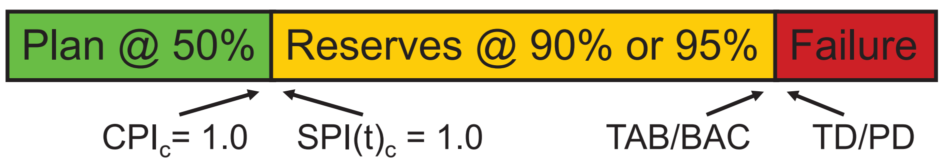
- An objective of project planning is to mitigate the foreseen risks with sufficient reserves in both cost and schedule duration.
- The application of the mathematics of statistics to the cost and schedule indicators from EVM and ES provides a method for linking risk to reserves and the forecast probability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

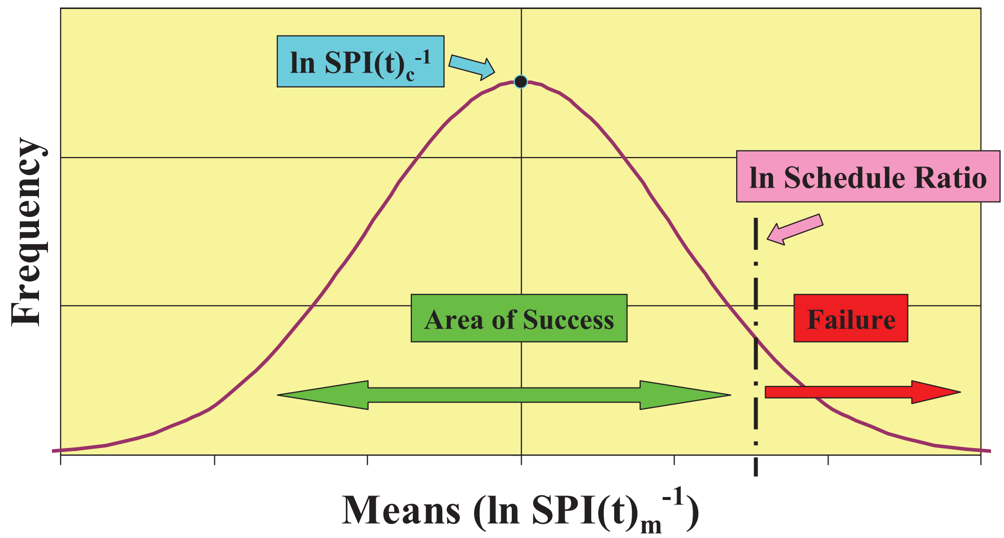
- Performance Outcome

$xPI_c^{-1} \leq 1.0$	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 ⇒ *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

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

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: σ_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

Demonstration – Statistical Planning

Exercise – Statistical Planning

- Familiarity with the Statistical Planning Calculator
  1) Open the Statistical Planning Calculator and review Instruction Notes
  2) Click on Reserv & Prob Calculator sheet and read instructions. Scroll down to review the Risk-Standard Deviation table.
  3) Copy values (BAC/PD, Reserve, σ, n) from Plnng Example Data sheet and paste into appropriate cells on Reserv & Prob Calculator sheet.
  4) Verify computed results to example data results on Plnng Example Data sheet.

Exercise – Statistical Planning

- Familiarity with the Statistical Planning Calculator
  5) Vary, one at a time, the entries for Reserve, σ, and n. Observe the changes to the Probability
     - Increasing Reserves → Increases Probability
     - Decreasing σ → Increases Probability
     - Increasing n → Increases Probability

       (while keeping the Ratio constant)

Statistical Planning Calculator

Statistical Planning Calculator

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

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

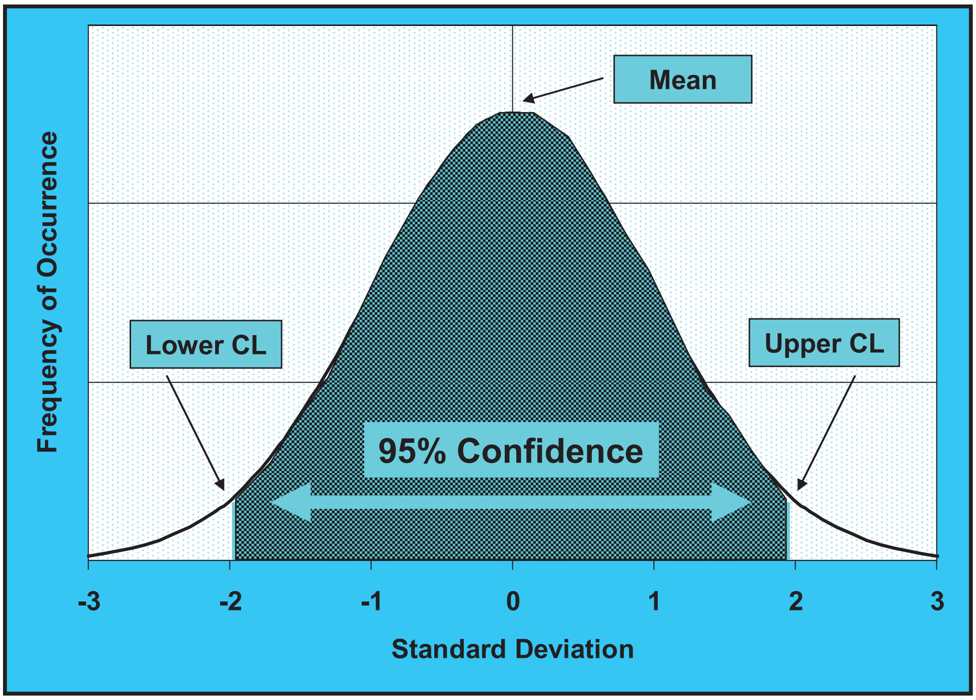
Mean = estimate of average from the sample

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



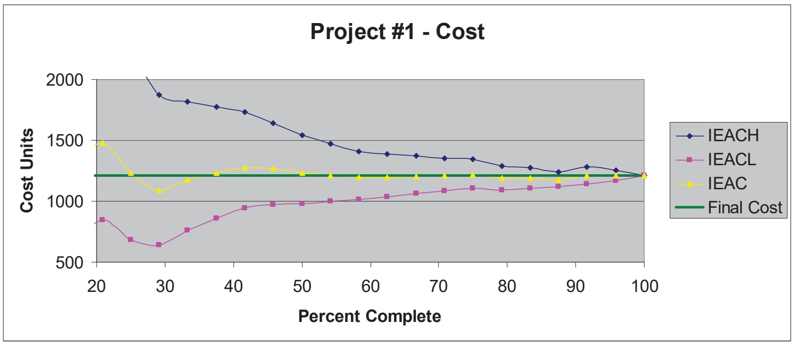
Complexity Elements

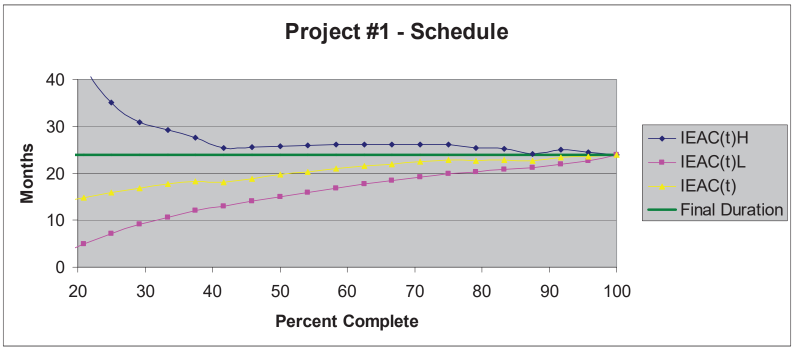
- Normality of Data
  - CPI & SPI(t) distributions appear lognormal
  - Mean is logarithm of cumulative value of index
  - $\sigma = \sqrt{(\Sigma(\ln \text{period index}(i) - \ln \text{cum index})^2 / (n - 1))}$
- Finite Population
  - $AF_C = \sqrt{((BAC - EV) / (BAC - (EV/n)))}$
  - $AF_S = \sqrt{((PD - ES) / (PD - (ES/n)))}$
- 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 index(cum) ± Z × (σ/√n) × AF
- Forecast at Completion
  - $IEAC_{(\text{low or high})}$ = BAC / e^($CL_{(\pm)}$)
  - $IEAC(t)_{(\text{low or high})}$ = PD / e^($CL(t)_{(\pm)}$)

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*)

Demonstration – Statistical Forecasting

Exercise – Statistical Forecasting

- Familiarity with the Statistical Forecasting Calculator
  1) Open the Statistical Forecasting Calculator (SFC) and its accompanying instruction document
  2) Read the instruction document and reference the calculator as needed for understanding
  3) Click the Example Data sheet. There are two sets of data. For the exercise use the set of data which has only PV and EV values.
  4) ES values are needed for the SFC Input Data Sheet. Open the ES Calculator and load the Example Data (*transpose the data on the Example Data sheet, then copy and paste <u>values</u> to the ES Calculator).* Copy and paste the calculated ES_{cum} results to the SFC Input Data sheet.

Exercise – Statistical Forecasting

- Familiarity with the Statistical Forecasting Calculator
  5) Make the following entries to the Project Data sheet:
     - Title 1: *Example Data*
     - Budget at Completion: *31,821*
     - Project Start Date: *1/1/2012*
     - Planned Duration: *27*
     - Note the computed value for the Planned Completion Date
     - Note the Statistical Forecast Confidence Level default value of 90%.

Exercise – Statistical Forecasting

- Familiarity with the Statistical Forecasting Calculator
  6) Click the Statistical Calculation sheet. Observe the computed results for IEAC(t), $IEAC(t)_H$, and $IEAC(t)_L$
  7) Click the Statistical Forecast Schedule (SFS) sheet and observe the graphs of the three IEAC(t) forecasts. Note that they converge and meet at the final duration.
  8) Click on the Statistical Forecast Schedule Date sheet, observing similar behavior to that seen on the SFS sheet.
  9) Change the Statistical Forecast Confidence Level on the Project Data sheet to 95% and 80%. Observe, the High and Low forecasts are wider spread at 95% and are narrower at 80%, respectively.

Statistical Forecasting Calculator

Statistical Forecasting Calculator

Statistical Methods - Recovery Probability

Recovery Probability

- Establishment of the TSPI threshold facilitates the probability calculation
- TSPI exhibits odd behavior …and lack of meaning for periodic values …statistical distribution unknown
  - *How can the probability be computed without discerning the statistical characteristics?*
- Solution ➡ Transform TSPI threshold to $SPI(t)_T$ function

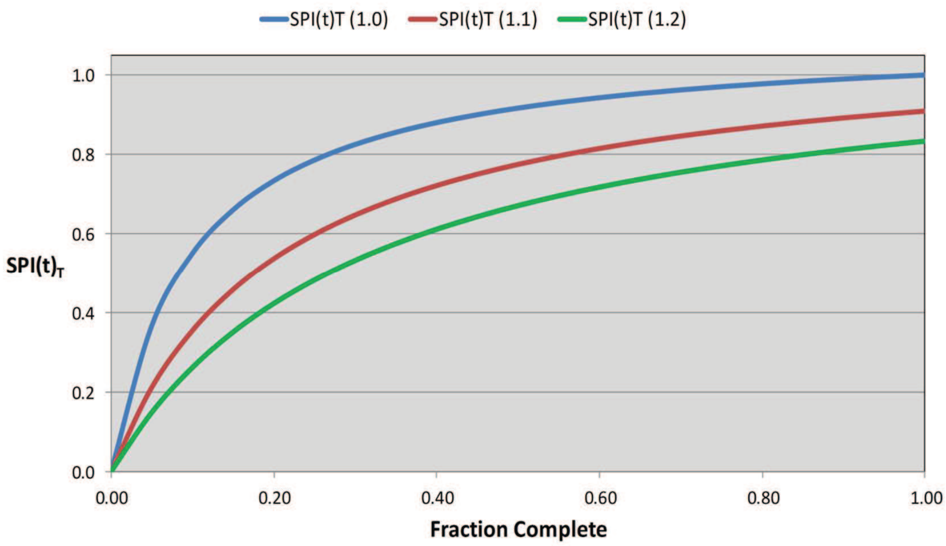
$$TSPI = 1.10 = (PD – ES) / (TD – AT) = (1 – ES\%) / (SR – ES\%/ SPI(t)_T)$$

$$SPI(t)_T = 1.10\ ES\% / (1.10\ SR – 1 + ES\%)$$

  - $SPI(t)_T$ function facilitates statistical comparison to SPI(t)

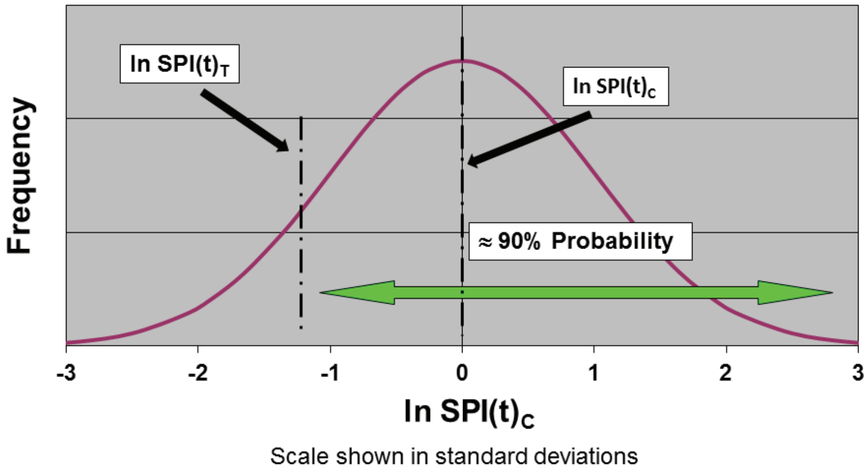
Behavior of Threshold Function

- Three plots illustrate the effect of various values of reserves; i.e., as values of SR



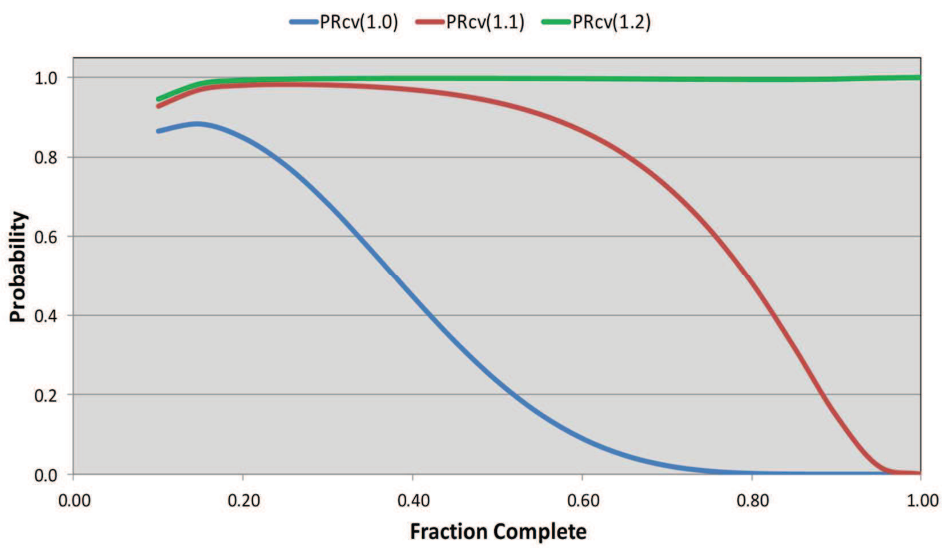
Recovery Probability Example

- The probability is determined from the area beneath the normal curve beginning at ln $SPI(t)_T$ and extending to plus infinity



Recovery Probability & Reserves

- The figure illustrates the influence of schedule reserve on the probability of recovery (PRcv)



Summary

- The value of 1.10 is very likely a valid threshold for TSPI …facilitating the probability of recovery calculation
- The calculation method incorporates the 1.10 value and the established lognormal characteristics of SPI(t)
- PRcv is used with TSPI, PO%, SPI(t), and IEAC(t) for making the decision to take recovery action
- The probability of recovery is foreseen to be a very useful aid in determining when project management intervention can be beneficial

Demonstration – Recovery Probability

Exercise – Recovery Probability

- Familiarity with the ES Probability of Recovery Calculator
  1) Open the ES Probability of Recovery Calculator. Read the Instructions and Interpretation of Results on the Data Input & Results sheet.
  2) Click on Prob Sched and Prob Cost sheets. The probability of recovery is computed on these sheets. Note that PRcv is graphed and the analysis results are displayed, as well.
  3) Use the data from the Example Data sheet to experiment and gain confidence.

Recovery Probability Calculator

Recovery Probability 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

- Relationships of special schedule performance indicators – *Down Time & Stop Work affect SV(t), Stop Work affects SPI(t)*
  - $iSV(t)_{per} = SV(t)_{per(nx)} + DT_{per}$ *(Look Up Table)*
  - $iSPI(t)_{cum} = SPI(t)_{cum(nx)}$ & $iSPI(t)_{per} = SPI(t)_{per(nx)}$
  - $iSV(t)_{per} = -1.000$ & $iSPI(t)_{per} = 0.000$ *(for SW condition)*
  - $iSV(t)_{cum}w/oDT = \Sigma\ iSV(t)_{per}$ *(DT = Down Time)*
  - $iSV(t)_{cum} = iSV(t)_{cum}w/oDT + DT_R$ *(DT_R = Down Time remaining)*

Note: $iSV(t)_{cum}w/oDT$ 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

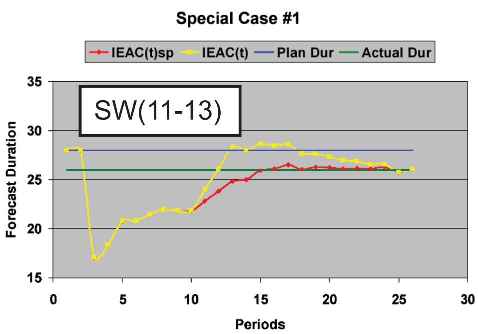
$$IEAC(t)_{sp2} = (PD - DT_T) / iSPI(t)_{cum} + SW$$

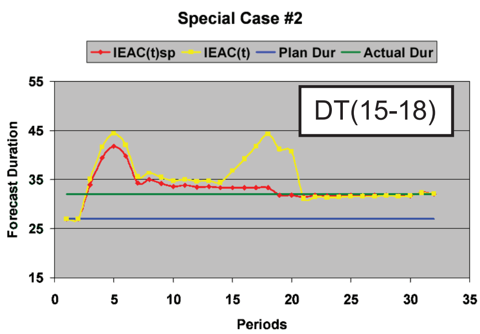
Forecasting Formula Derivation

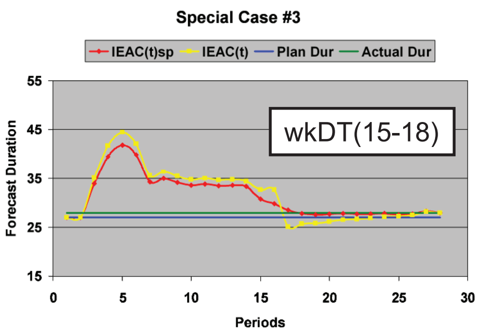
- Next DT_T is added. As down time periods occur they are totaled (DT_L) and subtracted.
- When $IEAC(t)_{sp2} < PD$, the number of down time periods between the forecast and PD are counted (DT_C) and subtracted
- The special forecasting formula becomes

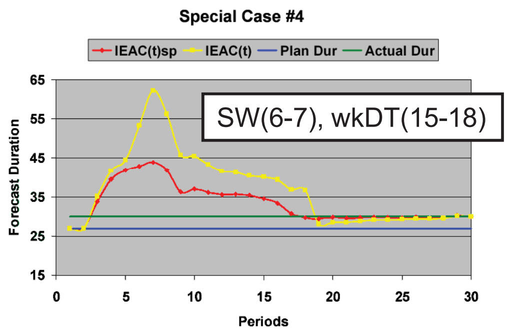
$$IEAC(t)_{sp} = (PD - DT_T) / iSPI(t)_{cum} + SW + DT_T - DT_L - DT_C$$

SW & DT Cases – Comparisons

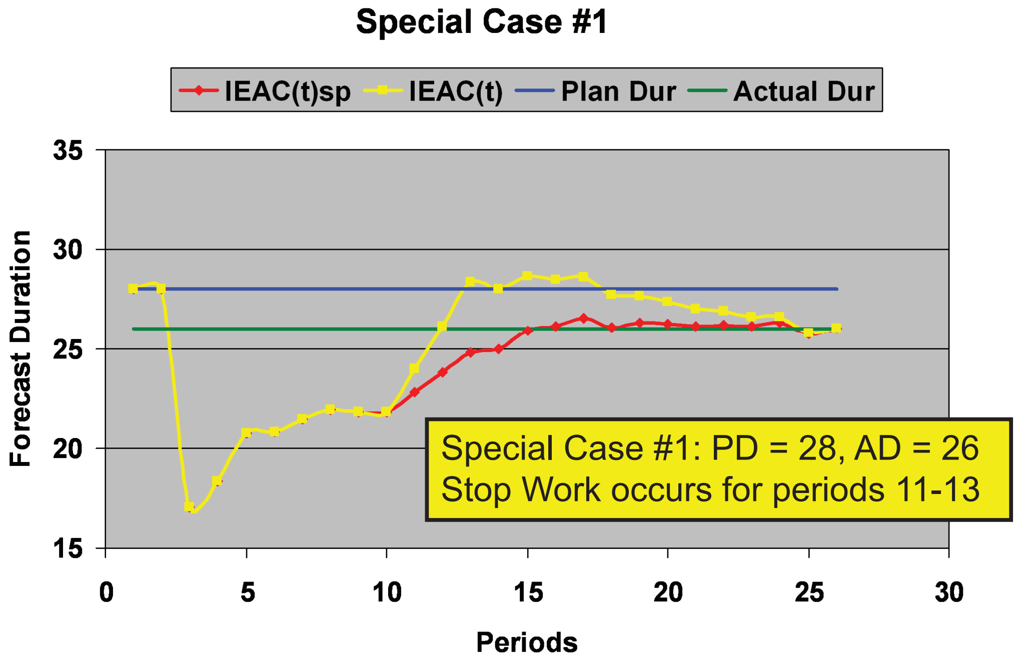




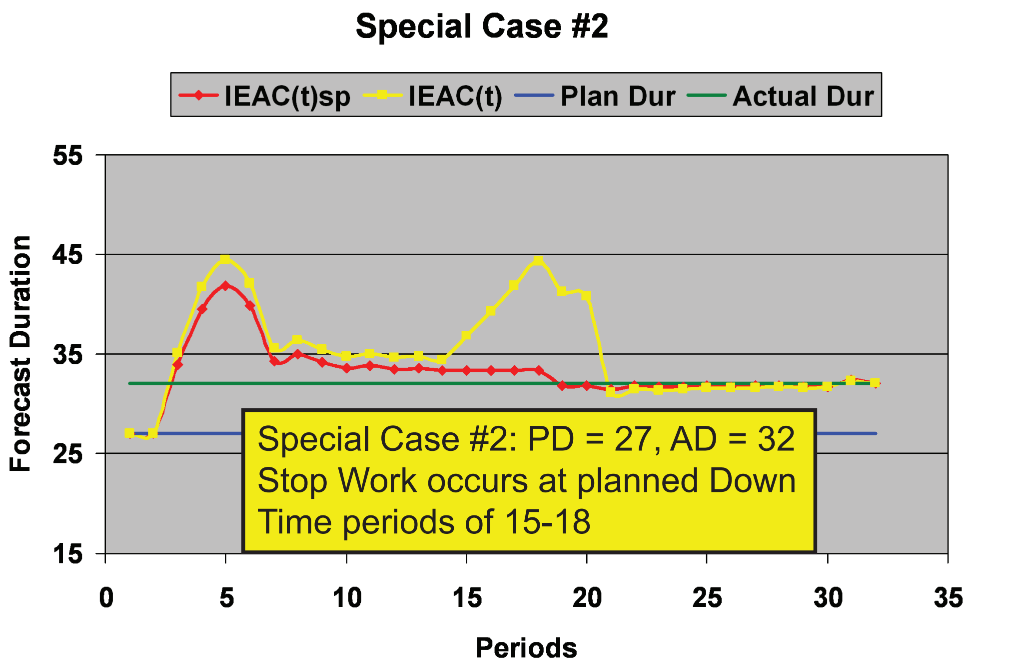




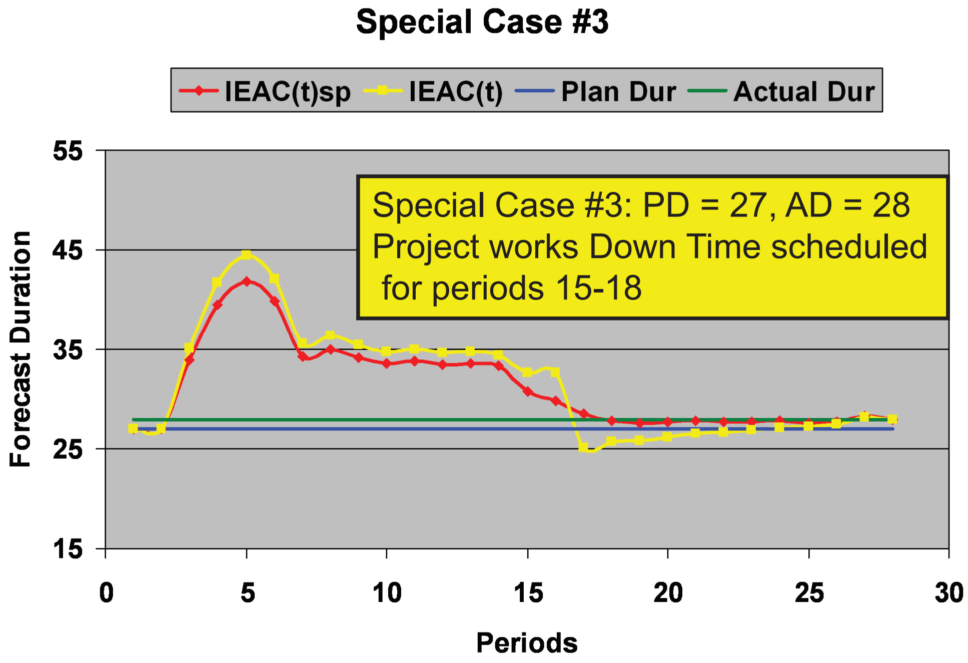
SW & DT Cases – Comparisons



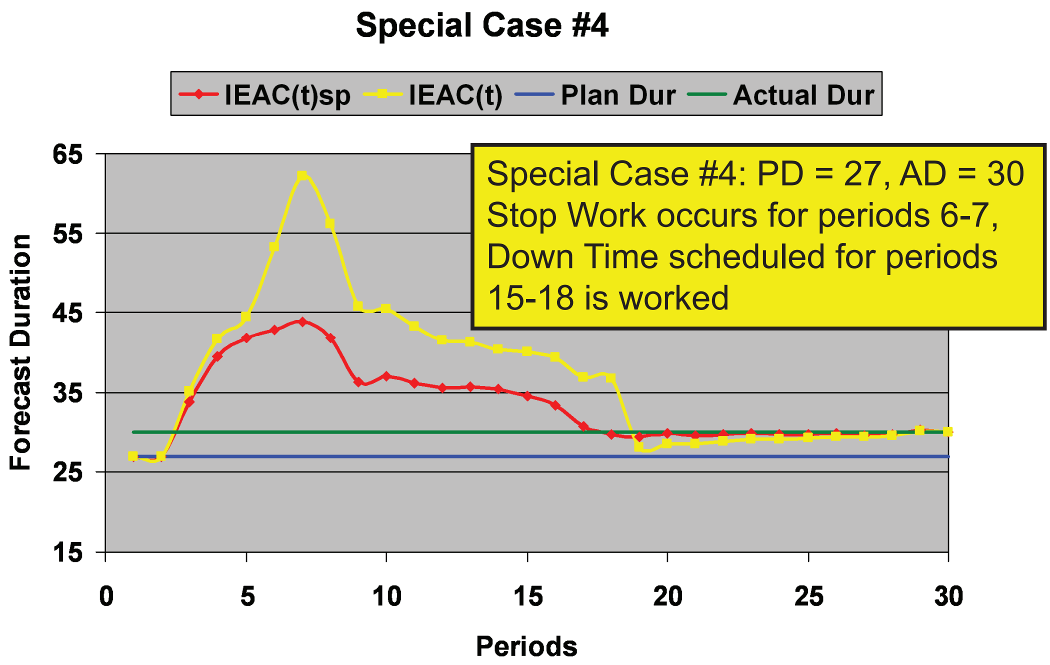
SW & DT Cases – Comparisons



SW & DT Cases – Comparisons

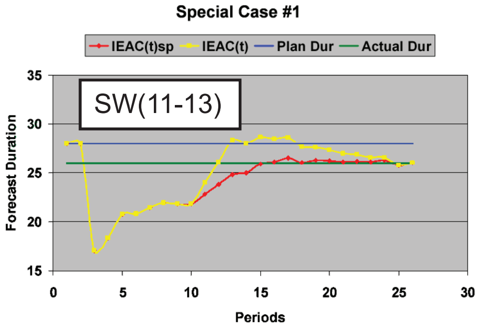


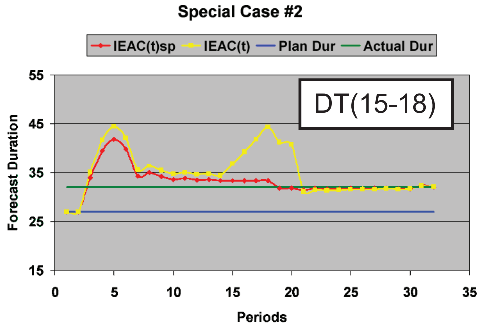
SW & DT Cases – Comparisons

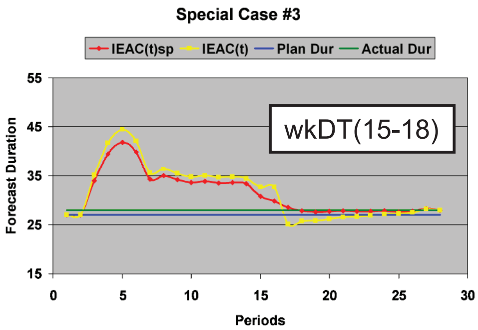


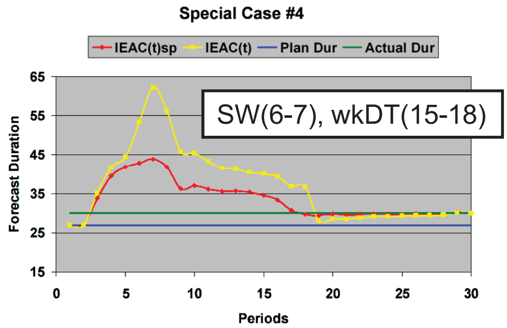
S

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,* distorts 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

Demonstration – Small Projects

Exercise – Small Projects

- Familiarity with the ES Calculator (special cases)
  1) Open the ES Calculator vs1f (special cases). Read the Special Case Instructions on the first sheet.
  2) Click on the Data Entry sheet. Data has been entered for example #4.
  3) Click on EScalc Special sheet. Explore the calculation sheet, noting especially the columns, Period, IEAC(t)sp, Comp Date.
  4) Click on Special Indicators sheet to review the effects of stop work and down time on schedule performance indicators.
  5) Click on Special Forecast sheet and observe the graph of the special forecast in comparison to the normal ES forecast.

Exercise – Small Projects

- Familiarity with the ES Calculator (special cases)
  6) Click on #4 Late Finish-mix stop-plan sheet; observe the graph is identical to the graph on the Special forecast sheet.
  7) Enter data from the other trial sheets and compare the Special Forecast sheet graph to the graph on trial sheet selected.
  8) Note that both the special case is a significant improvement to the normal forecast and that both always converge to the final duration.

Special Cases Calculator

Special Cases Calculator

Longest Path Forecasting

Longest Path Forecasting

- Practitioner and research evidence is compelling for applying ES project duration forecasting
- However, 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

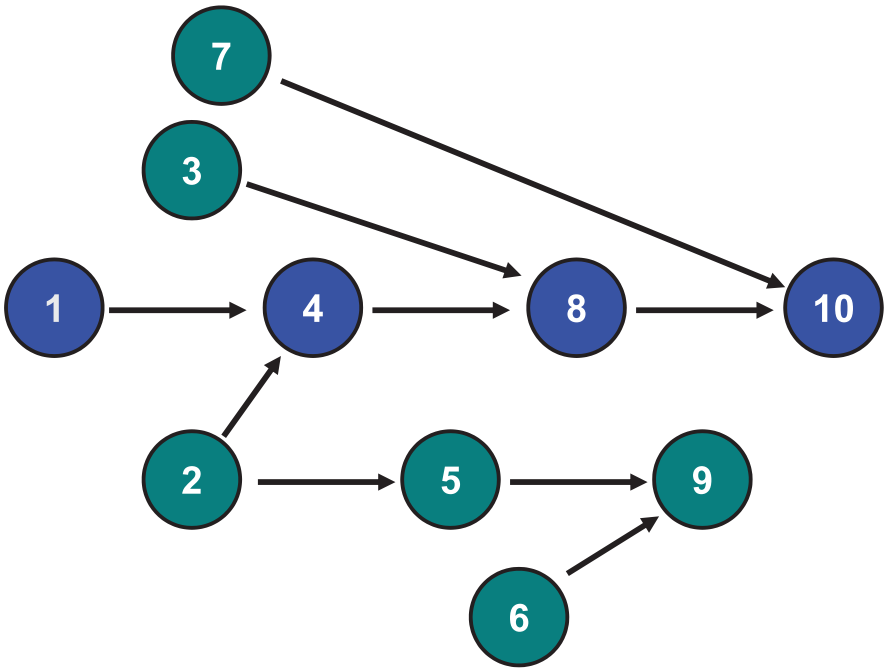
Longest Path Theory

- 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 Requirement / Anomaly Identify

- Fundamental …when EV increases, ES must as well
- Verify for identified LP forecasts

  $$ES(L) = PD \times AT / IEAC(t)_{LP}$$

- Anomaly identified for period 3

Performance Path	**** **** **** ES(L) by Period **** **** ****											
	1	2	3	4	5	6	7	8	9	10	11	12
1-4-8-10		1.48	3.21	5.12	5.56	5.45	7.03	8.21	8.18	10.00		
2-4-8-10			1.05	3.67	5.00	4.74	6.66	8.00	7.94	10.00		
2-5-9				5.00	5.96	6.79	7.00	6.81	7.66	8.73	9.36	10.00
3-8-10			2.50	4.16	5.00	4.74	6.66	8.00	7.94	10.00		
7-10				3.14	4.09	4.71	6.05	7.42	7.89	10.00		
6-9						6.55	7.00	6.40	7.41	8.64	9.31	10.00
Total Project		1.48	3.08	4.29	4.98	5.40	6.52	7.08	7.62	9.00	9.45	10.00

Reject Anomaly / Improve Forecast

Performance Path	**** **** **** ES(L) by Period **** **** ****											
	1	2	3	4	5	6	7	8	9	10	11	12
1-4-8-10		1.48	3.21	5.12	5.56	5.45	7.03	8.21	8.18	10.00		
2-4-8-10			1.05	3.67	5.00	4.74	6.66	8.00	7.94	10.00		
2-5-9				5.00	5.96	6.79	7.00	6.81	7.66	8.73	9.36	10.00
3-8-10			2.50	4.16	5.00	4.74	6.66	8.00	7.94	10.00		
7-10				3.14	4.09	4.71	6.05	7.42	7.89	10.00		
6-9						6.55	7.00	6.40	7.41	8.64	9.31	10.00
Total Project		1.48	3.08	4.29	4.98	5.40	6.52	7.08	7.62	9.00	9.45	10.00

Performance Path	**** **** **** Forecast by 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		
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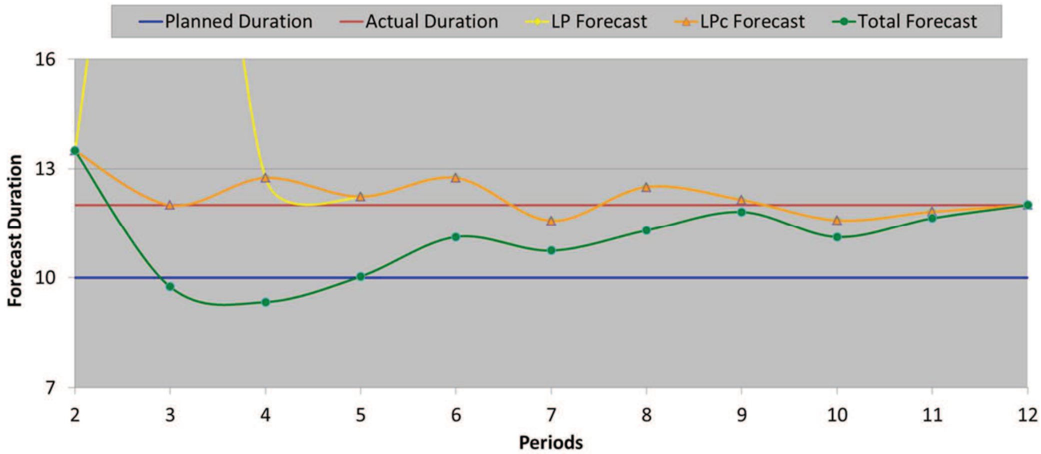
2-5-9				8.00	8.38	8.83	10.00	11.75	11.75	11.45	11.75	12.00
3-8-10			12.00	9.62	10.00	12.67	10.51	10.00	11.33	10.00		
7-10				12.75	12.24	12.75	11.57	10.78	11.40	10.00		
6-9						9.17	10.00	12.50	12.14	11.58	11.82	12.00
Total Project		13.50	9.75	9.33	10.03	11.12	10.74	11.29	11.81	11.11	11.64	12.00

ES-LP versus ES-T Forecasts



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

ES-LP Statistical Forecasting

- Initially – not believed possible
- Even if possible – overly burdensome and complex
- Nevertheless, the promise of ES-LP warrants the effort
- As discovered, implementation …IS SIMPLE
- Only requirement – ability to compute $SPI(t)_p$
- To obtain periodic SPI(t), all that is needed are periodic values of ES, regardless of their attribution …and thus
  - ES values from the total project will yield its set of statistical forecasts
  - ES(L) values provide associated Longest Path forecasts

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

Demonstration – Longest Path Forecasting

Exercise – Longest Path

- Examine Longest Path (LP) forecasting for a parallel task project
  1) Open Excel files, Exercise Longest Path (ELP) and ES-LP Calculator v1e. *(Note: Special Cases vs1f calculator is used when data includes Stop Work and/or Down Time).*
  2) Using PV and EV data from ELP, calculate IEAC(t) for Task 1, using vs1b. Enter computed results into the appropriate cells of the forecast table on Parallel Forecasts sheet. Repeat for Tasks 2 and 3, and Total Project.
  3) Observe IEAC(t)LP forecast values are displayed. Enter the final duration (FD) for periods 1 through 30.
  4) Examine the graph displayed, comparing the forecasts.

Longest Path Forecasting

ES-LP Calculator

Longest Path Forecasting

Longest Path
Example

Advanced Methods Summary

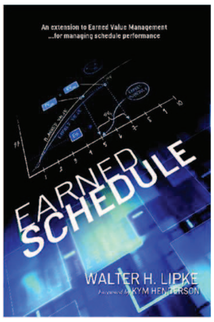
Advanced Methods Summary

- ES is shown to accommodate performance baseline changes …and Critical Path & Milestone analysis
- Detail analysis of schedule performance facilitated through Schedule Adherence …constraints/impediments
- SA provides capability to analyze rework and its impacts
- Methods for circumstances of down time and stop work conditions
- Statistical Methods for planning, forecasting, and project recovery
- ES-LP improves forecasting for highly parallel schedules

Application Help

Available References

- Earned Schedule Website
  http://www.earnedschedule.com/
- PMI® Standards for EVM & Scheduling and PMBOK / NDIA Guides / ISO EVM Standard
- *Earned Schedule* book (English, Japanese, Portuguese, Spanish)
  - Print
  - ePub (Nook & iPad)
  - Kindle
  - PDF



Application Support

- Explore the Earned Schedule website
  - Papers, Presentations, Calculators, Terminology
  - News, Tools, Training, Experts, Sites of Interest
  - Concept Description & Introductory Video
- 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
  - P-Factor Calculator
  - Statistical Forecasting Calculator
  - SA Index & Rework Calculator
  - Prediction Analysis Calculator
  - Probability of Recovery Calculator

Implementation Strategy

- Because you are already using EVM …*take the next step to applying Earned Schedule*
- 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 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?

- o They measure schedule performance in $$
- o They sometimes are erroneous
- o They can be poor predictors of outcome
- ☀ All of the above

Question #2

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

- o EVM measures schedule performance in $$
- ☀ PV & EV are constrained to BAC
- o They are not related to the network schedule
- o All of the above

Question #3

- What elements are required to compute Earned Schedule?

- o AT & EV
- o AC & PMB
- o EV & PV
- ☀ EV & PMB
- o 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?

- o I must be determined graphically
- o I = EV / PV
- ☀ $I = (EV – PV_C) / (PV_{C+1} – PV_C)$
- o $I = \Delta EV / \Delta PV$

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 project constraints and impediments, and future rework.

- ☀ True
- o 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?

- o Effective EV ≤ EV
- o Effective EV accounts for rework
- o More pessimistic early forecast of final duration
- ☀ All of the above
- o 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 …and much more
- 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!

TM