Earned Schedule

Forecasting Project Duration Increase From Rework

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Abstract

The introduction of Earned Schedule (ES), as an extension of Earned Value Management, led to the discovery of Schedule Adherence (SA). With SA, project managers can observe how closely the project execution follows the planned schedule, by monitoring the Schedule Adherence Index (SAI). SA provides methods for identifying tasks that may have performance restricted by impediments or process constraints, and other tasks that may experience rework in the future. As well, calculation methods have been created, utilizing SAI, for determining the rework generated from performing tasks out of their planned sequence. Thus, project managers have facility to assess the cost impact of rework. Rework obviously impacts project cost, but it must, also, increase project duration. This presentation takes another step in the evolution of ES. A method is developed for determining the duration increase caused by rework.

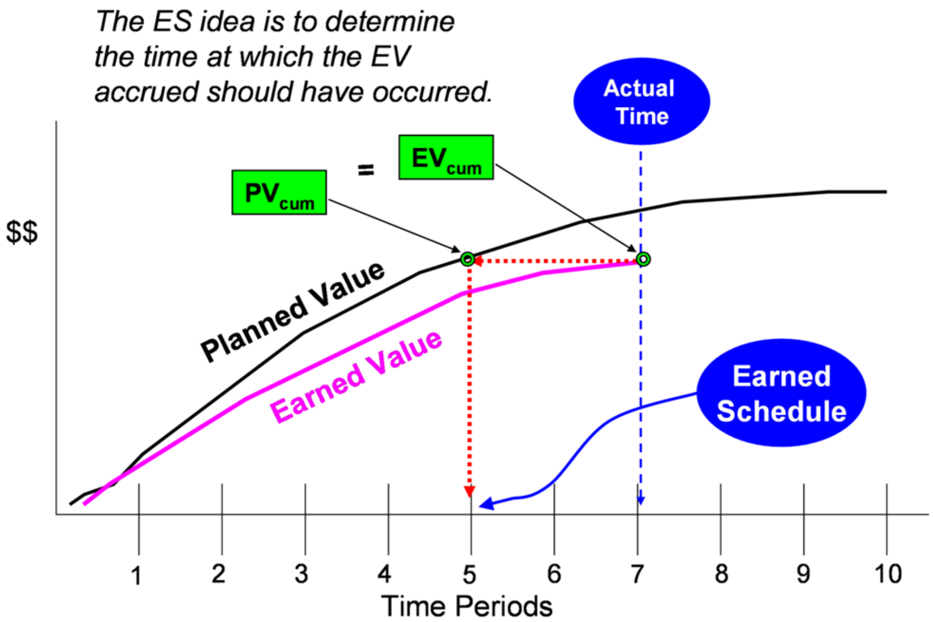
Objective

- Understand how rework derives from poor schedule performance
- Understand schedule adherence relationship to rework, project cost and duration
- Understand the simulation process creating the data for analysis
- Understand the mathematical models relating duration increase to rework and performance efficiency
- Be able to compute duration increase from rework and performance efficiency

Overview

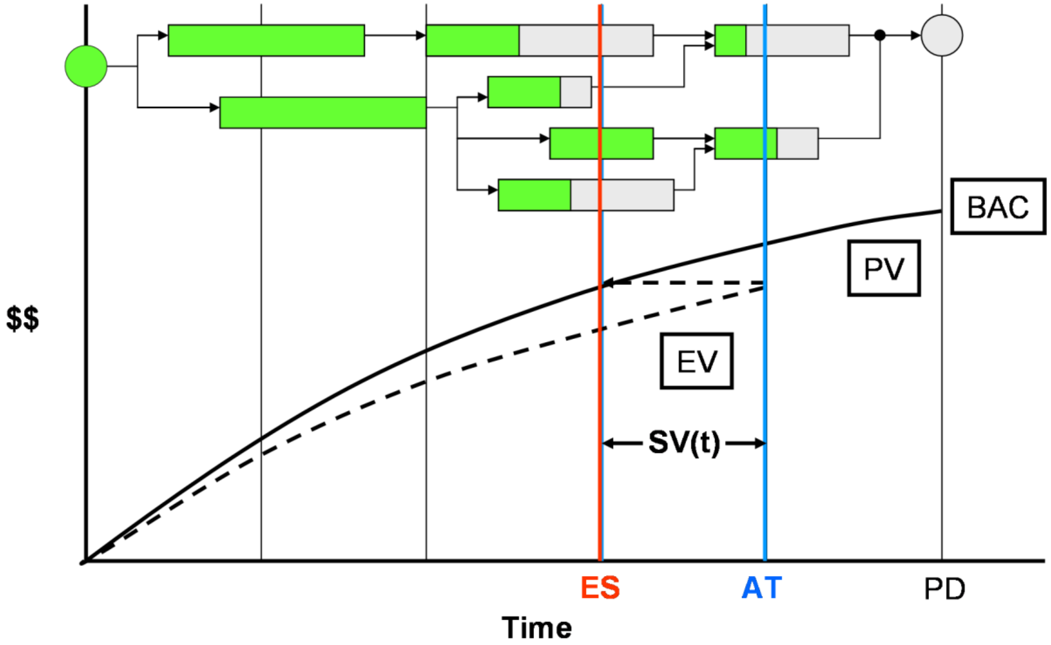
- Introduction – Earned Schedule & Schedule Adherence
- Method for Examining Duration Increase
- Simulation Description
- Output Analysis
- Parametric Models: DI% = f(SPI(t))
- Linear Model: DI% = f(R_{wk}%, SPI(t))
- Summary

Earned Schedule



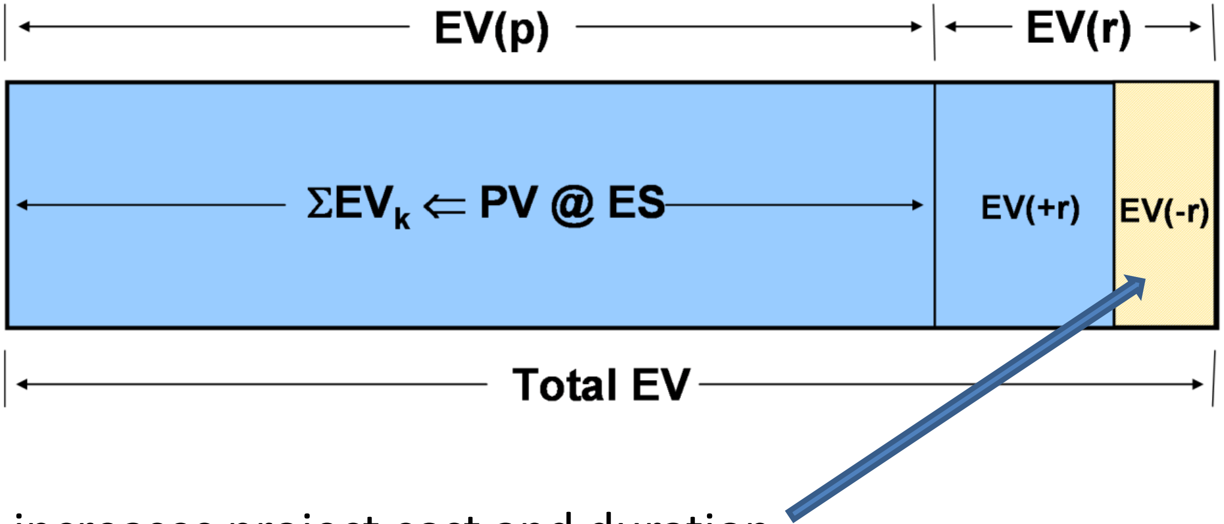
Time based schedule performance efficiency: SPI(t) = ES / AT

Schedule Adherence



- Ratio of aligned to total accrued EV – termed "P-factor"

Introduction / Rework



- Rework increases project cost and duration
- Methods developed to forecast total rework for completed project

Examine Duration Increase

- Difficult and complex problem
- Simulator constructed
  - Randomly varies periodic EV performance
  - Rework induced utilizing the P-factor
  - Project duration lengthening observed
  - Output: project duration with and without rework, total rework, total rework percent, duration increase, duration increase percent, average of the P-factor over the project execution, and SPI(t) at completion

Simulation Description

- Ten projects are simulated simultaneously
- Each has the same set of input variables: BAC, PD, multipliers for the periodic EV, probabilities for selecting particular multipliers, and an initial value for the P-Factor
- Outputs of each simulation are entered to a table and then averaged to become a record representing a specific set of inputs
- For all of the simulations, BAC = 100 and PD = 50 …thus, the base periodic value for EV is 2.00

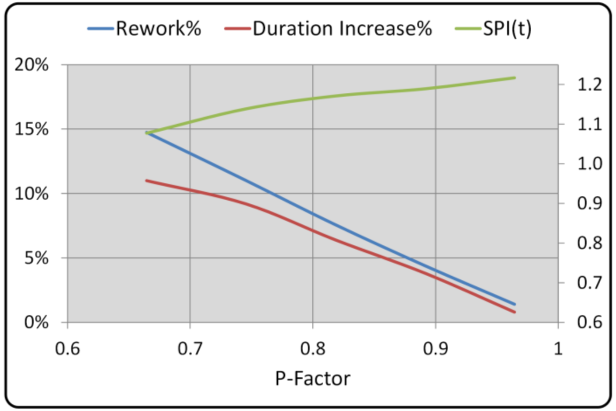
Simulation Description

- Three sets of multiplying factors were applied to the base EV to generate early, on-time, and late finish outcomes
- Each scenario performance (early, on-time, late) was skewed in the simulations by randomly applying probability of occurrence to each of the multiplying factors
- Applying 3 probability sets to the 3 scenarios yields 9 conditions for the 10 performance simulations …providing a good range of outcomes for examination.

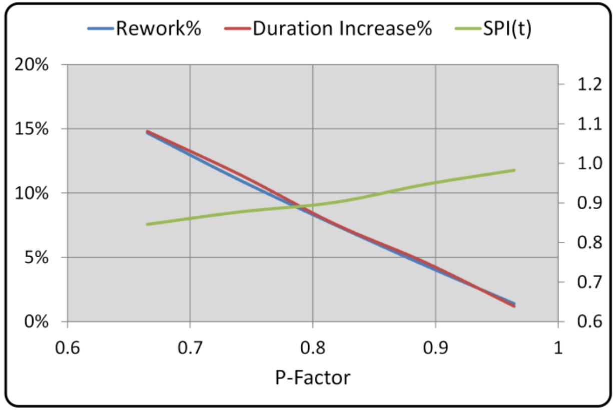
Simulation Description

- The P-factor was varied during the simulations of the 9 conditions to create six levels of rework (16%, 13%, 10%, 7%, 4%, 1%)
- Each of the 9 conditions described previously was simulated for each of the 6 levels of rework, creating 54 sets of results for analysis.
- Each set was averaged across the 10 simulations to obtain the outputs described earlier
- The rework values generated by the simulations were scaled to have agreement with the forecast output of the SAI and Rework Calculator

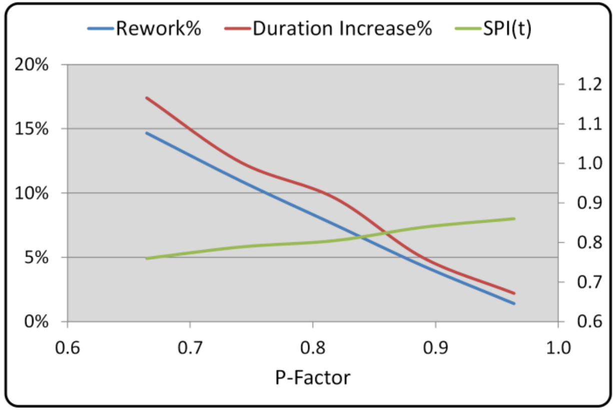
Output Analysis



Good Efficiency



Moderate Efficiency



Poor Efficiency

Output Analysis

- The linear relationship between the P-Factor and R_{wk}% is seen in each graph …(coefficient of correlation, r = 0.9939)
- Significant observation from the graphs is that rework is not a consequence of schedule performance efficiency
  - Regardless of the SPI(t) value, the line representing R_{wk}% appears in the exact same location in each graph
- The figures indicate a negative relationship between SPI(t) and DI% …as SPI(t) becomes larger, DI% decreases

Output Analysis

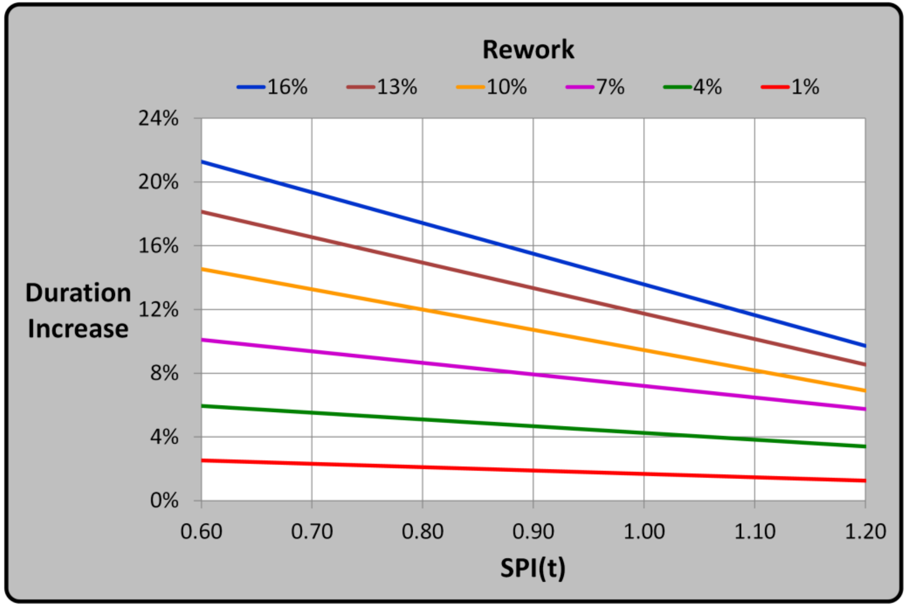
Rework	16%	13%	10%	7%	4%	1%
r value	.9769	.9728	.9625	.9698	.8443	.5454

DI% vs SPI(t) - Coefficient of Correlation (r)

Level of Significance (α)	0.10	0.05	0.01
Critical Value (df = 7)	0.584	0.666	0.798

Critical Values for r

Parametric Models



Rework%	Models
16%	$DI\%_{16} = 0.3284 - 0.1927 \times SPI(t)$
13%	$DI\%_{13} = 0.2773 - 0.1599 \times SPI(t)$
10%	$DI\%_{10} = 0.2217 - 0.1272 \times SPI(t)$
7%	$DI\%_{7} = 0.1445 - 0.0725 \times SPI(t)$
4%	$DI\%_{4} = 0.0849 - 0.0424 \times SPI(t)$
1%	$DI\%_{1} = 0.0380 - 0.0212 \times SPI(t)$

Parametric Models

- Correlation of DI% with SPI(t) has been determined for 6 levels of rework only
- Should rework percentage forecast be a value different from one of the six, its linear model for DI% and SPI(t) is not defined
- Additional predictive models could be created for various values of R_{wk}%, but the number needed becomes impractical
- An alternative is the application of interpolation

Parametric Models - Example

Reported values

SPI(t) = 0.850 and R_{wk}% forecast = 14%

Apply the parametric models

$DI\%_{13} = 0.2773 - 0.1599 \times 0.850 = 14.14\%$

$DI\%_{16} = 0.3284 - 0.1927 \times 0.850 = 16.46\%$

Interpolation calculation

$DI\% = DI\%_{13} + (DI\%_{16} - DI\%_{13}) \times (14\% - 13\%)/(16\% - 13\%)$

$DI\% = 14.14\% + (16.46\% - 14.14\%) \times 1/3$

$DI\% = 14.91\%$

Linear Model

- It is observed that as R_{wk}% increases the intercept and the slope values for the associated DI% model increase, as well

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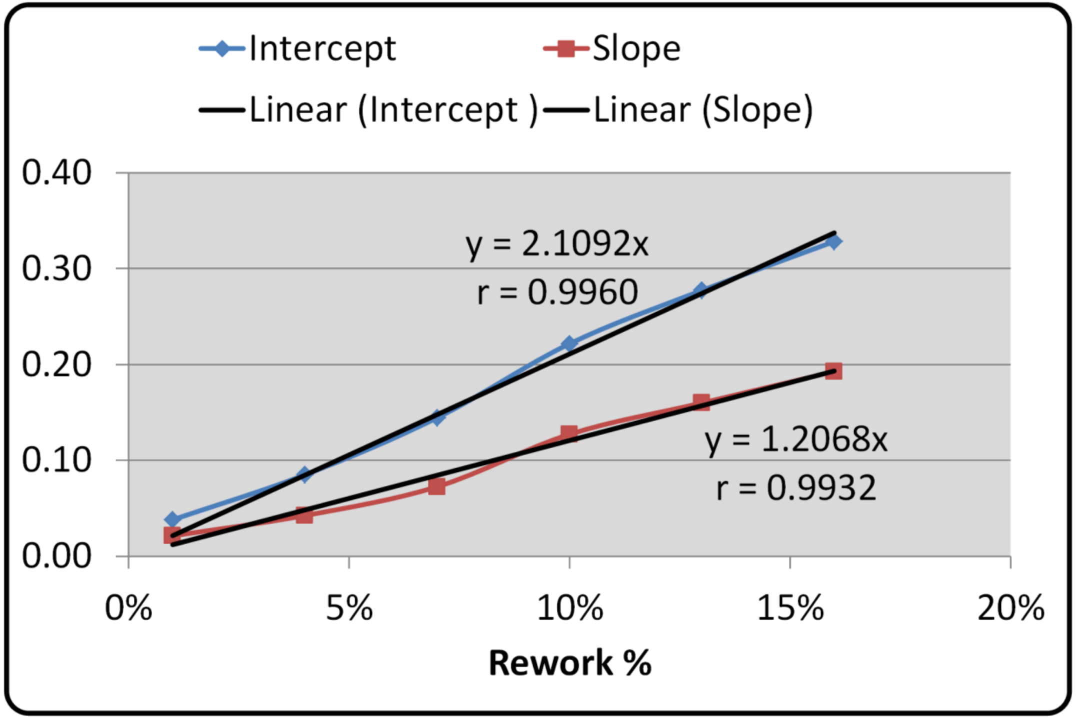
Linear Model

- Should a relationship exist between these variables, the ability to forecast DI% from any R_{wk}% value less than 16% can be made without the error implicit in the interpolation method
- Should the relationship be strong, it would be reasonable to believe that the range could be extended somewhat beyond the 16% limitation

Linear Model



Linear Model

- The graphs were made using the origin as a 7th data point …

  It is a reasonable assumption that both the intercept and slope should equal 0.0 when R_{wk}% equals 0.0

- The r values for intercept (0.9960) and slope (0.9932) are extremely close to 1.0, indicating a very strong linear relationship …

  This is verified by comparison to the CVs for df = 5 provided in the table

Level of Significance (α)	0.10	0.05	0.01
Critical Value (df = 5)	0.669	0.755	0.875

Linear Model

- From the equations shown in the graph, the DI% forecasting model can be derived:

  Intercept (I) = $2.1092 \times R_{wk}\%$

  Slope (S) = $1.2068 \times R_{wk}\%$

- The general construct for the linear model is:

  DI% = Intercept – Slope $\times$ SPI(t)

- Substituting for Intercept and Slope:

$$DI\% = (2.1092 - 1.2068 \times SPI(t)) \times R_{wk}\%$$

Linear Model

- Using the R_{wk}% and SPI(t) values from the previous numerical example, the derived linear model can be compared to the interpolation result:

$$DI\% = (2.1092 - 1.2068 \times 0.850) \times 14\% = 15.17\%$$

- The two computation methods produce values that are very close, 15.17% versus 14.91% …

  Certainly the linear model is easier to use and likely has less error

Linear Model

- The model does have limitations
  - When SPI(t) is equal to 1.74776 (2.1092 divided by 1.2068), DI% equals 0.0 for any R_{wk}% value
  - When SPI(t) is greater than 1.74776, nonsensical negative values are computed for DI% …although SPI(t) greater than or equal to 1.74776 is possible, it is very seldom achieved
  - The model is expected to provide good results when $R_{wk}\% \leq 20\%$ and $SPI(t) < 1.74776$

Linear Model

- Application notes
  - Multiplying DI% by PD computes the forecast duration increase
  - Useful formula: $D_o = D_w - DI$

    $D_o \Rightarrow$ Project duration without rework

    $D_w \Rightarrow$ Project duration with rework

    $DI \Rightarrow$ Project duration increase
  - From these simple calculations, the project manager is informed of when the project could have completed if rework was avoided
  - This knowledge promotes better planning and schedule execution
  - The *SAI, Rework, and Duration Increase Calculator* is available from the ES website (www.earnedschedule.com)

Calculator - Example

Schedule Adherence Index & Rework Estimate								
BAC	$1,200							
Measures	Status Point	1	2	3	4	5	6	7
	EV	$240	$360	$600	$840	$1,080	$1,200	#N/A
	P	0.200	0.500	0.700	0.820	0.870	1.000	#N/A
Calculations	C	0.200	0.300	0.500	0.700	0.900	1.000	
	f(r)	0.866	0.789	0.611	0.398	0.144	0.000	
	EV(r)	$192	$180	$180	$151	$140	$0	
	BAC - EV	$960	$840	$600	$360	$120	$0	
SA Index	SAI	0.173	0.169	0.183	0.167	0.168	0.000	
Rework	By Period	$21	$21	$42	$42	$40	$10	
	Cumulative	$21	$41	$84	$126	$166	$176	
	Forecast	$187	$183	$193	$186	$186	$176	

Calculator - Example

***							
Status Point	1	2	3	4	5	6	7
Percent Complete	0.200	0.300	0.500	0.700	0.900	1.000	#N/A
Budget At Completion	$1,200						
Rework Forecast%	15.59%	15.27%	16.12%	15.47%	15.50%	14.66%	#N/A
SPI(t)	0.500	0.750	0.799	0.843	1.000	0.920	
Planned Duration	5						
Duration Increase%	23.47%	18.39%	18.46%	16.90%	13.99%	14.65%	
Duration Increase	1.17	0.92	0.92	0.84	0.70	0.73	

Summary

- The concept of Schedule Adherence is derived from ES analysis
  - Assess impact of performing project tasks out of their planned sequence
  - It is probable that rework will be required at some future time
- To understand and examine the impact of rework on project duration, simulation of project performance was created
  - 54 combinations of rework and performance conditions were simulated simultaneously for 10 projects and subsequently averaged for analysis

Summary

- From the sets of results, two correlations were observed: R_{wk}% to the P-Factor, and DI% to SPI(t)
  - The correlation of R_{wk}% to the P-Factor demonstrated that rework is not a consequence of schedule performance efficiency
- The DI% to SPI(t) correlation was tested for each of the six rework percentages examined
  - Strong correlations were observed for all with the exception of the 1% rework parameter
  - R_{wk}% parametric models were derived from the linear correlations

Summary

- Interpolation method described for calculating DI% from two project status measures, R_{wk}% and SPI(t)
- Linearity of intercept and slope of the six parametric models allowed for the creation of the linear model:

$$DI\% = (2.1092 - 1.2068 \times SPI(t)) \times R_{wk}\%$$

- To promote management application and model verification, the *SAI, Rework, and Duration Increase Calculator* is made available on the ES website (www.earnedschedule.com)

Thank You!!