The Best of Both Worlds: Combining Parametric Cost Risk Analysis with Earned Value Management Using Bayesian Parameter Learning

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Agenda

- Cost and Earned Value
- Probabilistic View
- A Bayesian Approach to Combining Cost S-Curves and Earned Value Data
- Examples





Risk Curve

Innovation Drives Uncertainty

 Applies to innovative projects

- Uncertainty is due to incomplete knowledge
- NASA projects are highly innovative and typically take several years to develop



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"When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind."

– William Thomson, also known as Lord Kelvin (1889)

Today, we discuss a method for measuring the uncertainty in the cost to complete as the project proceeds.





The Bayesian View

Why Bayesian Risk Analysis?

- Motivating factor with Bayes, project progress (or lack thereof) can be used to update cost and schedule risk analyses during a project
- Helps us assess the cone of uncertainty
- Bayesian analysis is the math of uncertainty
 - Uncertain quantities are random variables specified by PDF's
 - Bayes Theorem: Random variables can be updated with new evidence
- It works with small data.







The Evolution of the Cost Estimating Process

COST SCHEDULE ESTIMATION AND EVALUATION SECTION .

- As a project begins development, probabilistic parametric cost estimates are developed and updated
- Later in development, earned value data is relied upon more





Using PDFs to Measure Risk







Parametrics or Earned Value? Yes, I'll Take Both!

- Parametric estimating and earned value statistics are often used by two different groups
- There are a variety of informal methods for combining the two
- Bayes' Theorem provides a rigorous mathematical method to combine these two sources of information to improve the accuracy of probabilistic estimates at completion











The Bayesian Approach

- Parametric cost estimates form the prior
- The evidence consists of expenditure and completion rates



The Rev. Thomas Bayes





Two Ways to Visualize Uncertainty







Examples *Example 1: Near Constant*

COST SCHEDULE ESTIMATION AND EVALUATION SECTION

Spending is close to the planned rate.



Observation	AC	% Complete	Cost Rate
0	1.25	0.25	5.01
1	2.33	0.47	4.99
2	3.40	0.68	4.98
3	4.50	0.90	5.00





Example 1 Results



Examples

Example 2: Recovery

Cost Schedule Estimation and Evaluation Section

Spend is initially at an abovebudget rate but ultimately gets on track.



Observation	AC	% Complete	Cost Rate
0	1.47	0.25	5.90
1	2.62	0.47	5.62
2	2.92	0.68	4.27
3	4.49	0.90	4.99





Example 2 Results







Bayesian Approach to EAC

Cost Schedule Estimation and Evaluation Section

Main Computation

- The EVM data we have is the series
 - $O_n = (ACWP_n, \%Complete_n)$
 - This ratio, $ACWP_n$, /%Complete_n is the costrate, cr_n
- If we have cost_rate and the %complete, then we can compute

 $EAC = ACWP + (cost_rate)(1-\%complete)$

- However, the cost_rate is uncertain and so we need the PDF of the cost_rate
- With the PDF we use Monte Carlo analysis to compute the PDF of the EAC

Computing the Cost_Rate

- We model the cost_rate as a logistic PDF with loc parameter = u and scale parameter = σ .
- Note that both of these parameters are uncertain with their own PDFs.
- We use a 2d version of Bayes theorem of Bayes theorem to learn their PDFs. This is called 'Bayesian Parameter Learning' (Cantor, 2023)

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With these PDF's, use Monte Carlo analysis to find the EAC PDF as an empirical PDF of the samples of u and σ .



Internal Results





Bayesian Approach to EAC

Cost Schedule Estimation and Evaluation Section

Main Computation

- The EVM data we have is the series
 - $O_n = (ACWP_n, \%Complete_n)$
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 $EAC = ACWP + (cost_rate)(1-\%complete)$

- However, the cost_rate is uncertain and so we need the PDF of the cost_rate
- With the PDF we use Monte Carlo analysis to compute the PDF of the EAC

For a more complete explanation, see our paper, The Best of Both Worlds: Combining Parametric Cost Risk Analysis with Earned Value Management Using Bayesian Parameter Learning.



Computing the Cost_Rate

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Internal Results



Strengths

Cost Schedule Estimation and Evaluation Section

- Mathematically sound approach to combine cost risk analysis with earned value management
 - Elementary probability theory
- Use both subjective and objective information
- Uses EVM data should be tracking
- Early warning of a possible issue





Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov



Challenge - Requires Cultural Change

- Need for the cost and earned value communities to unite
 - Requires coordination across organizations
 - Data sharing
 - Single viewpoint
 - Respond to questions about overruns
 - One source of information







Final Points

• We showed some simple textbook examples.

- The technique scales up to large projects using various aggregation techniques.
- This approach for managing schedule and cost uncertainty is being integrated into Intaver Institute's RiskyProject tool.

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COST SCHEDULE ESTIMATION AND EVALUATION SECTION

Summary and Next Steps

Cost Schedule Estimation and Evaluation Section

- With this approach, you can update risk analyses conducted not only at major milestones but also throughout delivery using project progress statistics
- Next ideas
 - Apply to schedule analysis
 - Apply to JCL analysis updates
 - Consider quantitative portfolio management across directorates and even all of NASA.
 - Technical enhancements
 - Nonlinear spending plans
 - Include both fixed and variable costs
 - Causal Bayesian net models to account for externalities.



The Wheel of Fortune in Carmina Burana





Thank you for your time and attention

Questions??





4/29/2024

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