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

Murray Cantor
Cantor Consulting, LLC

Christian Smart
Jet Propulsion Laboratory
California Institute of Technology

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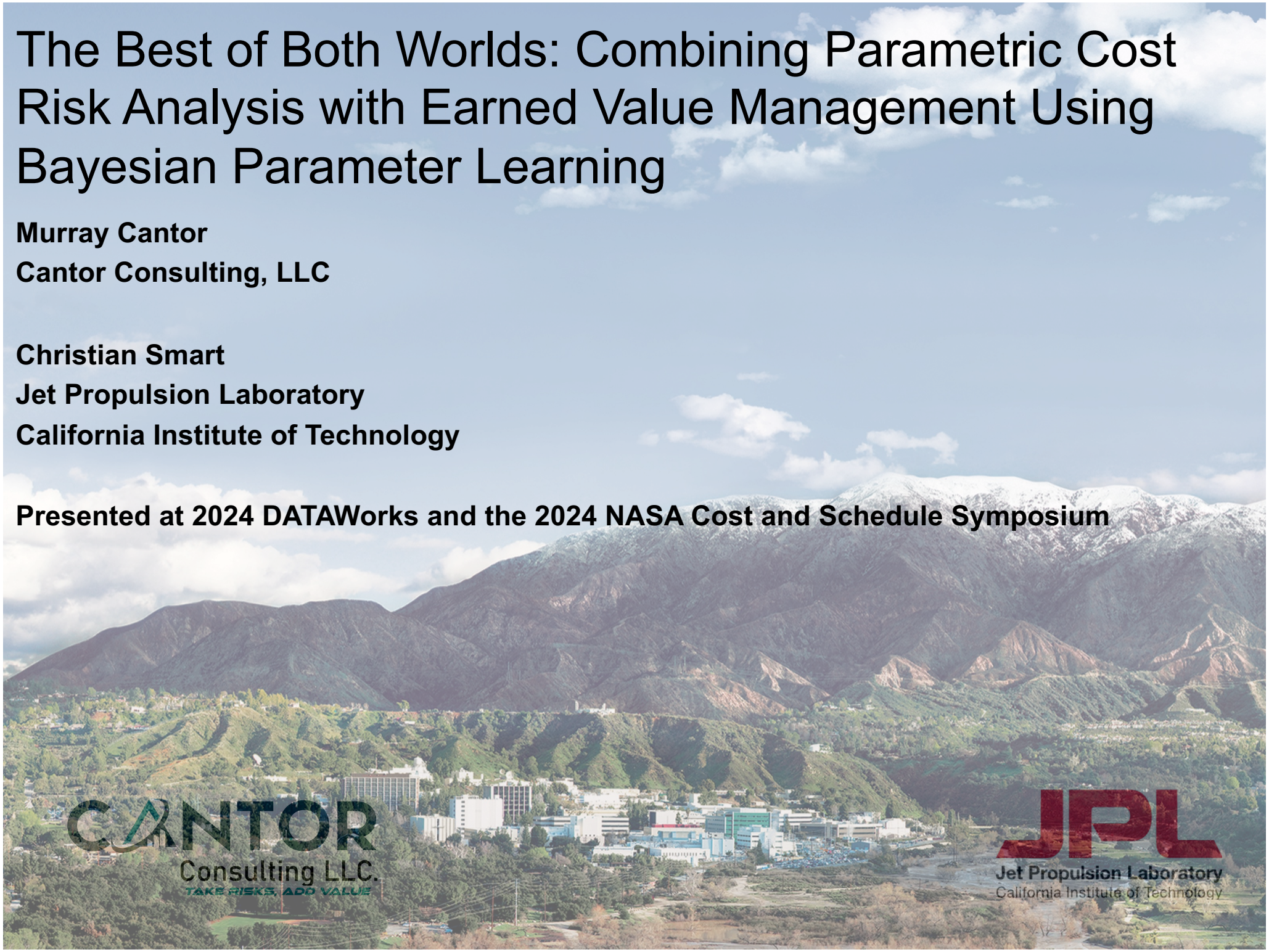

Agenda

- Innovation and Uncertainty
- An Investment Perspective
- A Bayesian Approach to Combining Cost S-Curves and Earned Value Data
- Examples
- Futures

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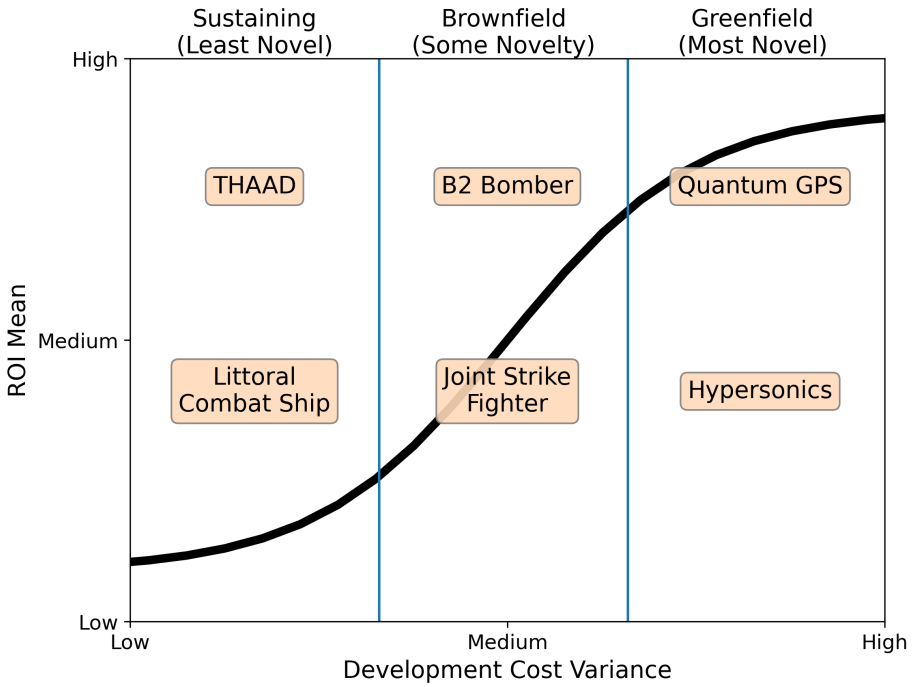
Risk Curve

Innovation Drives Uncertainty

- This applies to innovative projects
- Uncertainty is due to incomplete knowledge
- Defense projects are often highly innovative and typically take several years to develop



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The Main Idea

PPM's Success Depends on Managing Uncertainty

Projects are successful if they deliver or exceed the anticipated ROI.

PPM investments differ from financial investments because:

- The benefits, dev costs, after - deployment costs, and schedules are uncertain.
  - Benefits can be either monetary or mission fulfillment (e.g., kill/cost)
- One can take actions to improve the odds of getting the desired ROI.

"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 of completing the project as it proceeds.

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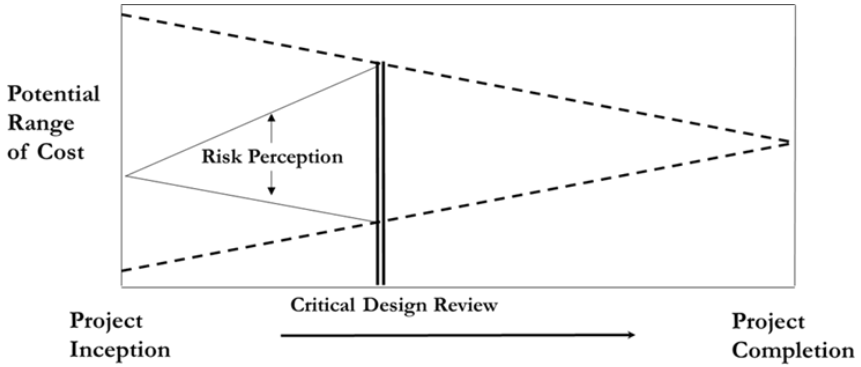
The Bayesian View

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
- 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
- Helps us assess the cone of uncertainty with small data



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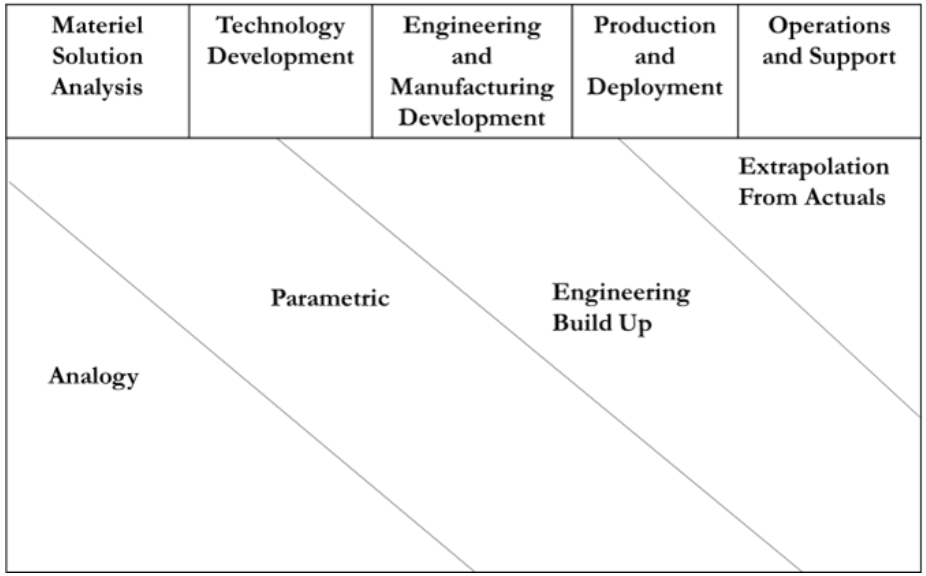
The Evolution of the Cost Estimating Process

- As a project begins development, probabilistic parametric cost estimates are developed and updated.
- Later in development, earned value data is collected and can provide input to Bayesian refinement.
- The outcome is more informative and can be relied on for decision support



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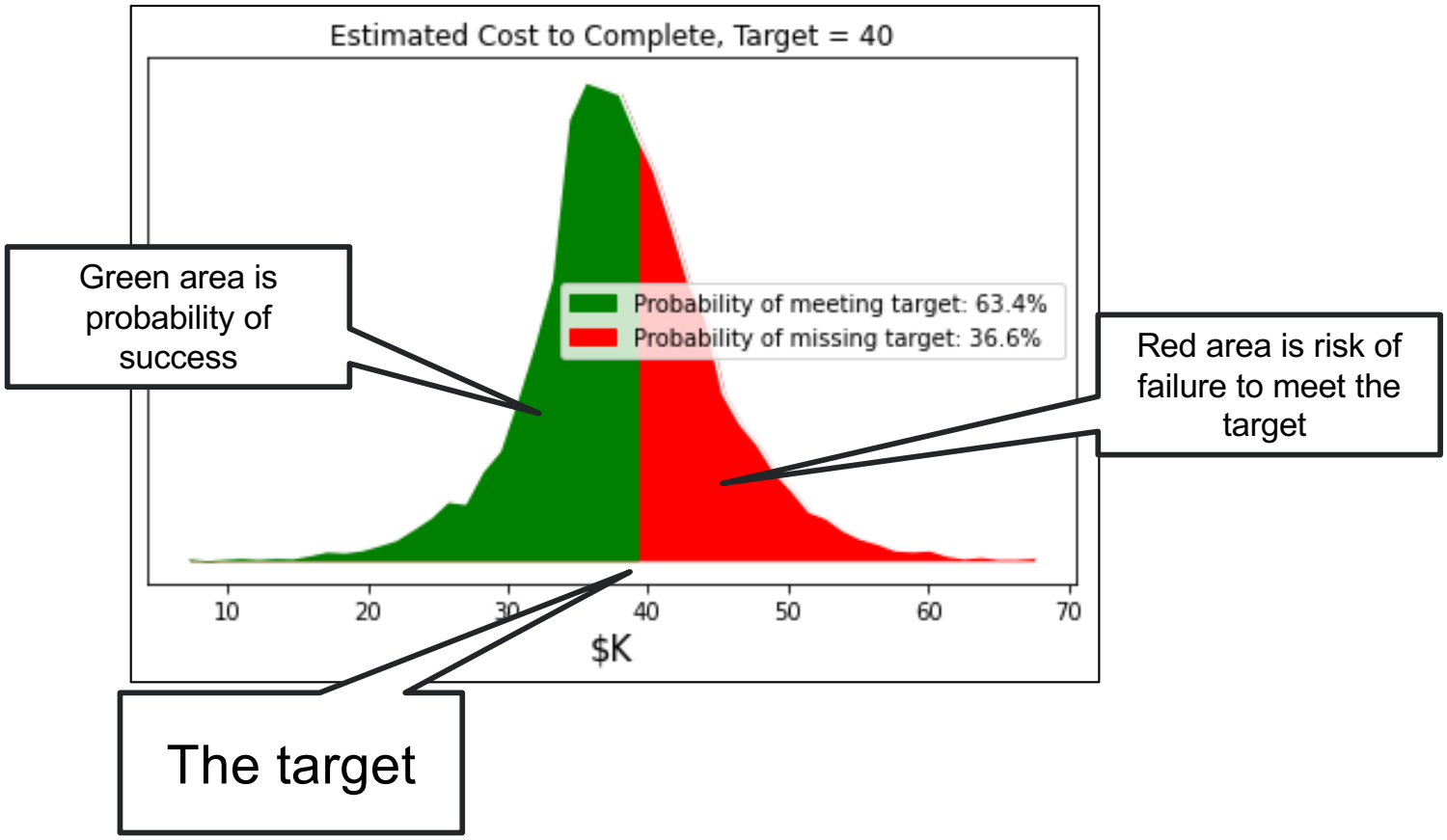
Using PDFs to Measure Risk



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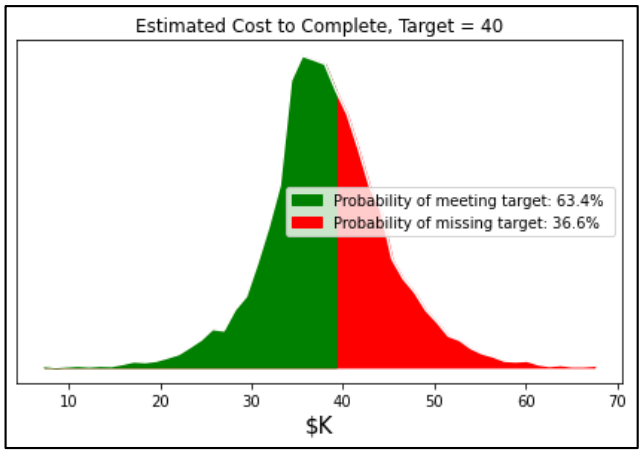
Parametrics or Earned Value? Yes, I'll Take Both!

- 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



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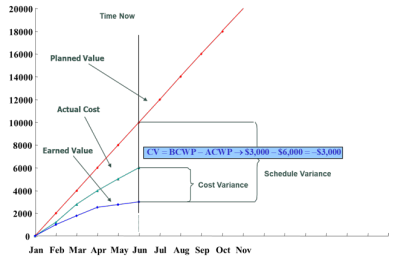

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The Bayesian Approach

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

The Rev. Thomas Bayes

$$P(Var|observations) = \frac{P(Observations|Var)P(Var)}{P(Observations)}$$

Posterior — Likelihood — Prior — Marginal

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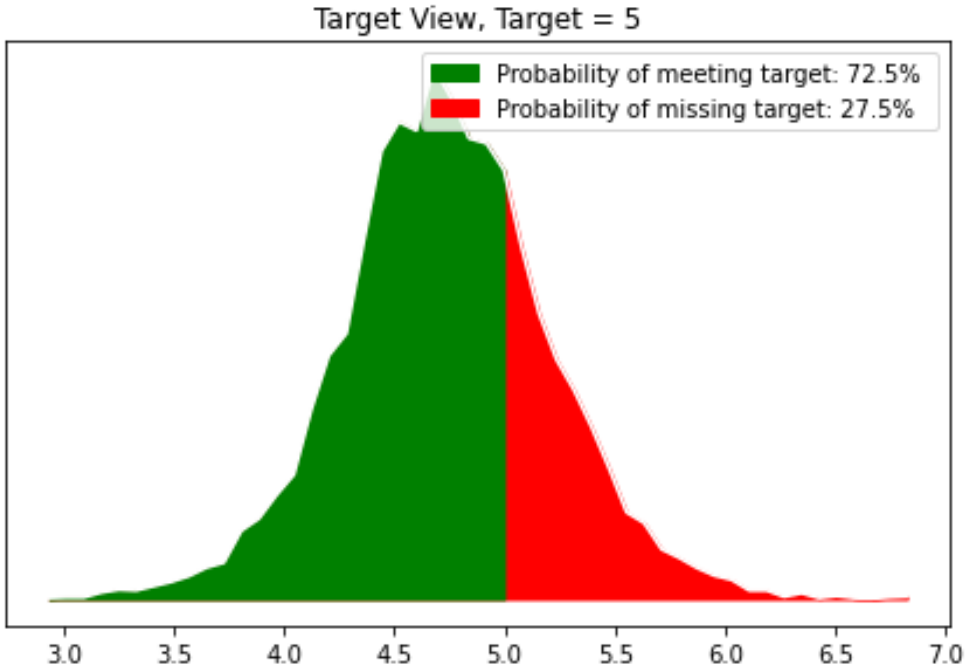
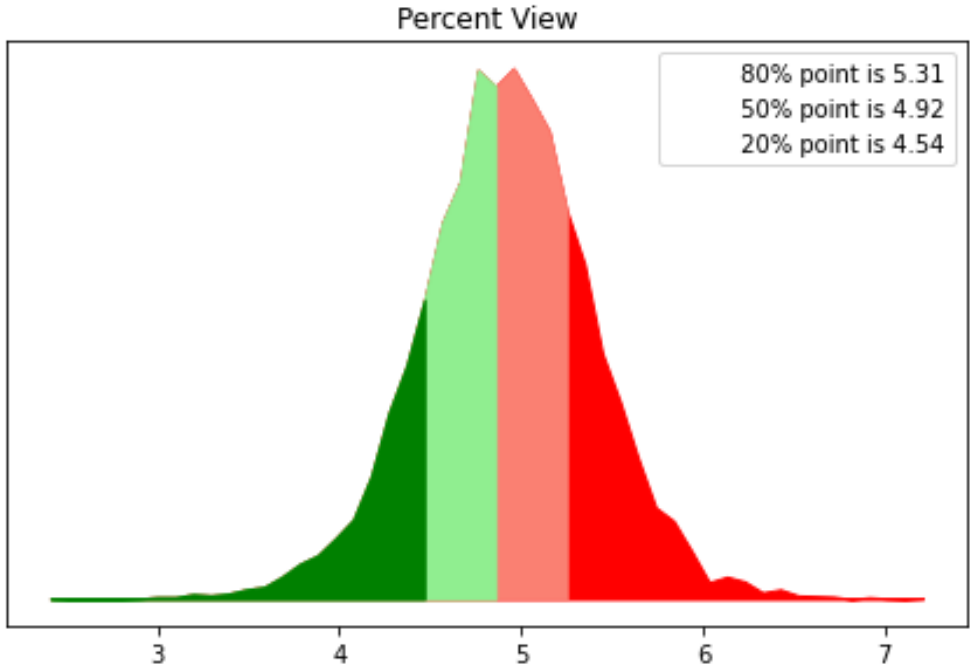
Two Ways to Visualize Uncertainty



Likelihood of meeting or beating the target



How much will you miss or beat the target

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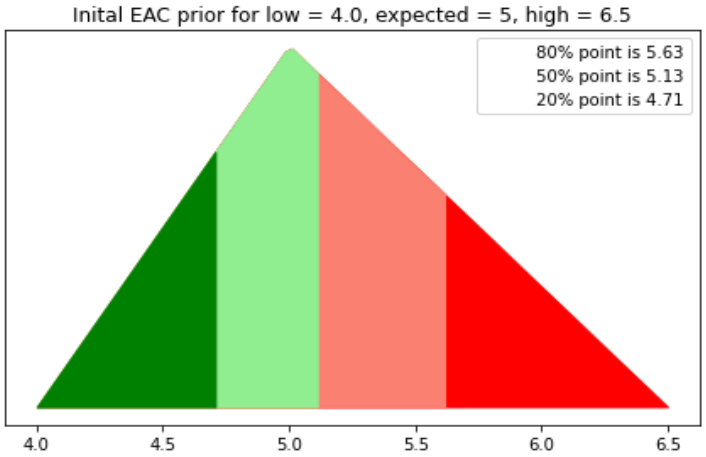
Examples

Example 1: Near Constant

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

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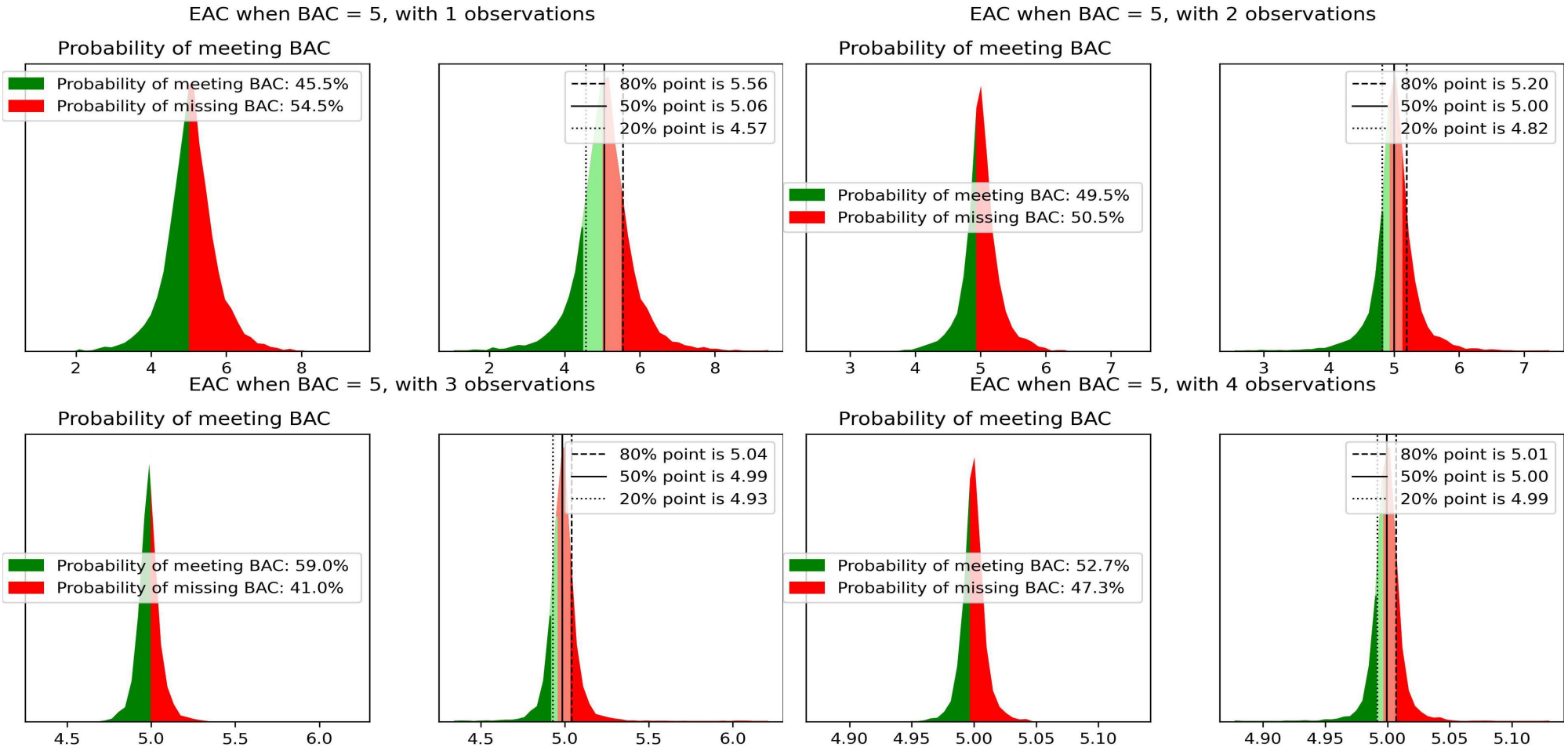
Example 1 Results



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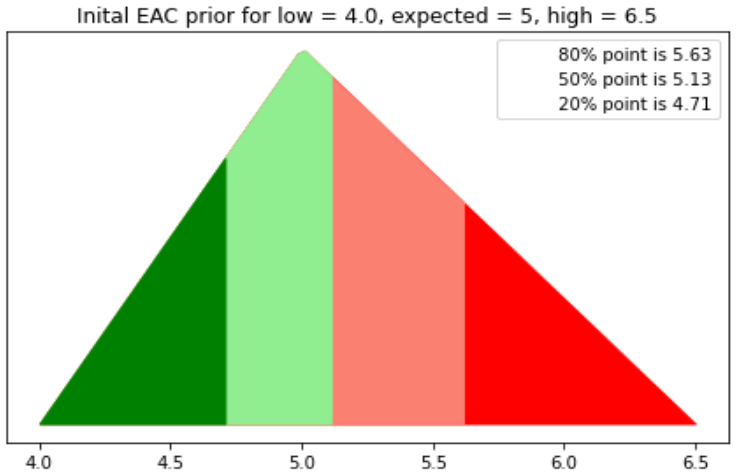
Examples

Example 2: Recovery

Spend is initially at an above-budget 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

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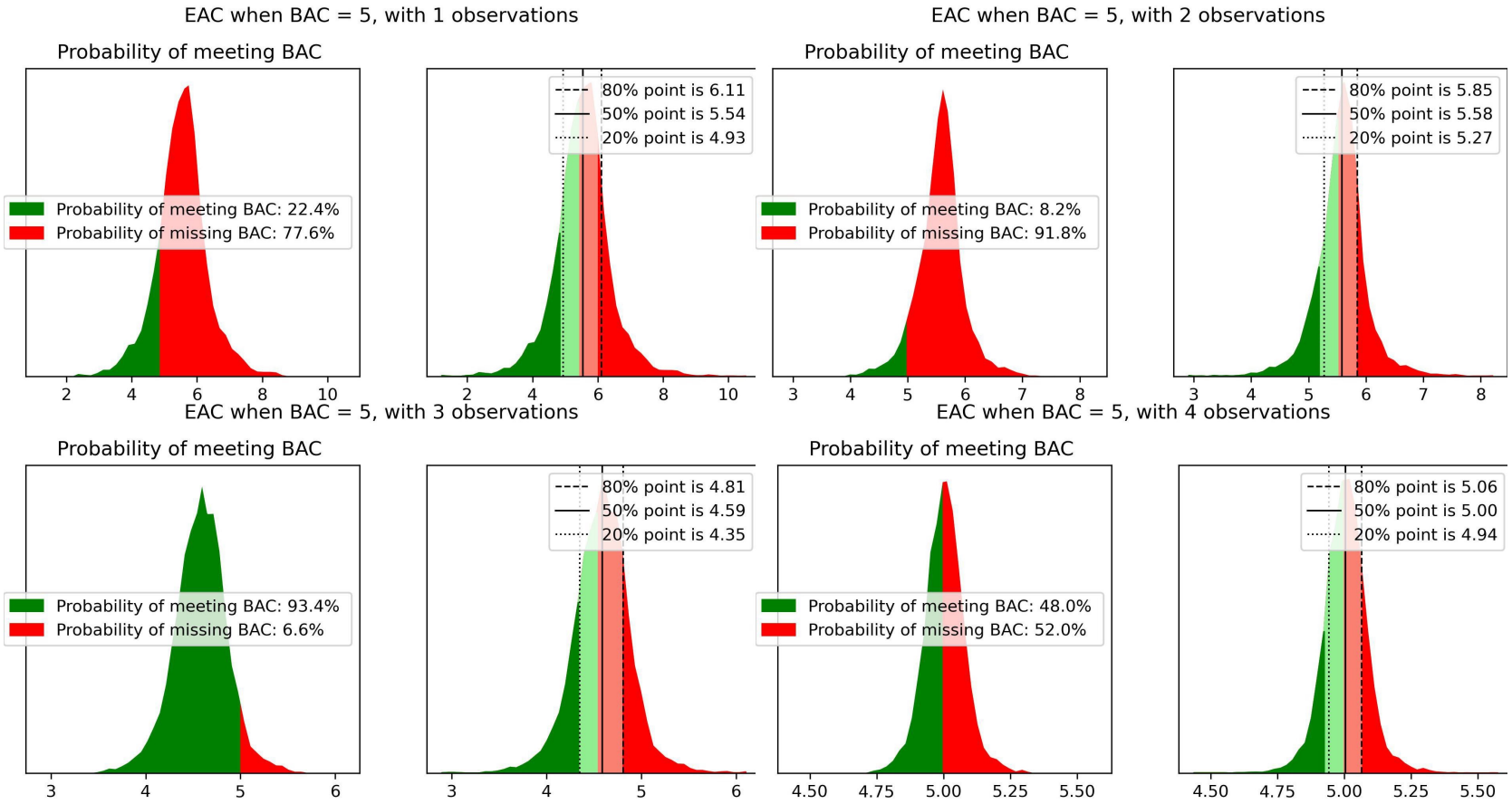
Example 2 Results



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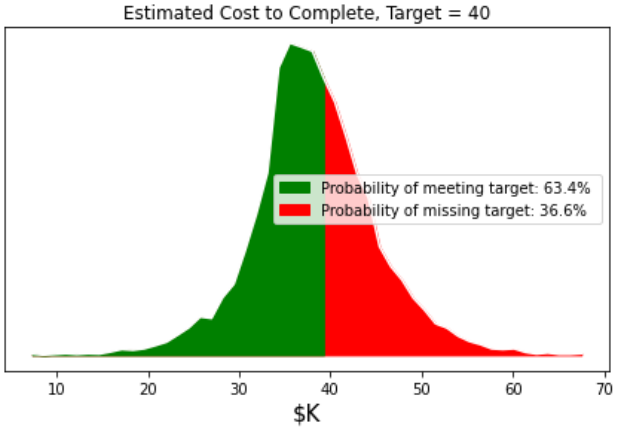
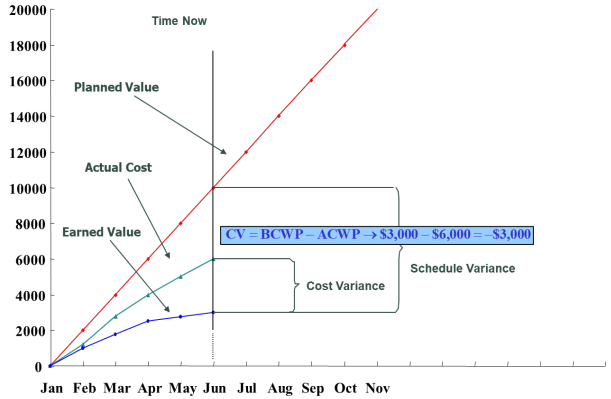
Strengths

- 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





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Challenge - Requires Cultural Change

- Need for the cost management, schedule management, and risk management communities to integrate.
  - Data sharing
  - Single viewpoint

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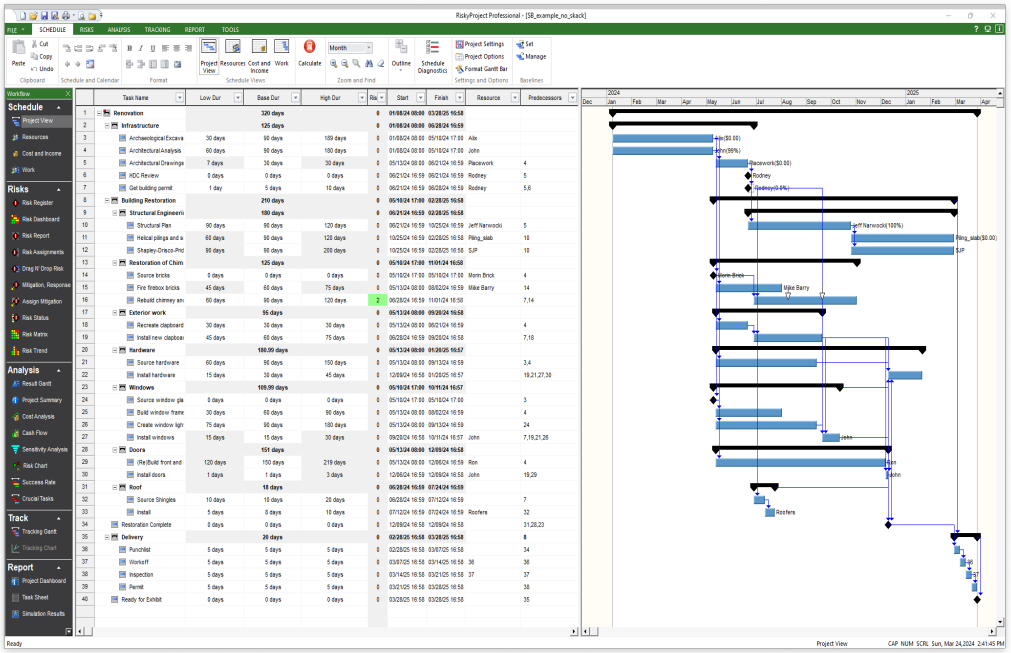
More to Come

- The authors of this presentation, along with Glen Alleman, are writing a book on applying these ideas, which will be published by CRC Press next year.
- This schedule and cost uncertainty management approach will be integrated into the Intaver Institute's RiskyProject tool next release.
- Developing ROI joint probability approach and tools that are available on a consulting basis.
- Future integration with digital twins



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Thank you for your time and attention

Questions??

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Bayesian Approach to EAC

Main Computation

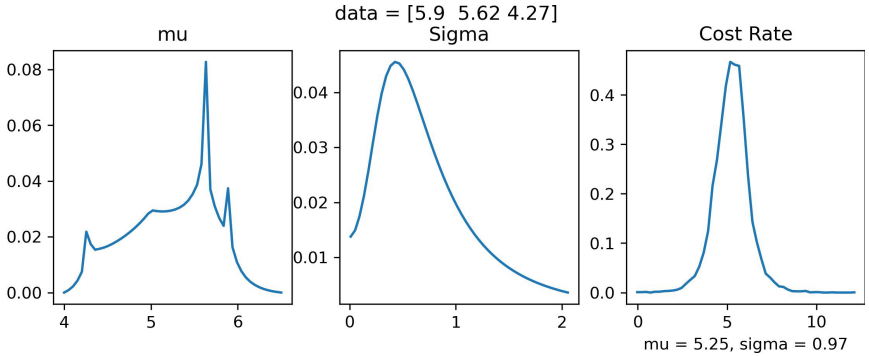
- The EVM data we have is the series
  - O_n = ($ACWP_n$, $\%Complete_n$)
  - This ratio, $ACWP_n$, /$\%Complete_n$ is the cost-rate, cr_n
- If we have cost_rate and the %complete, then we can compute

  $EAC = ACWP + (cost\_rate)$(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

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

- 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)
- 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

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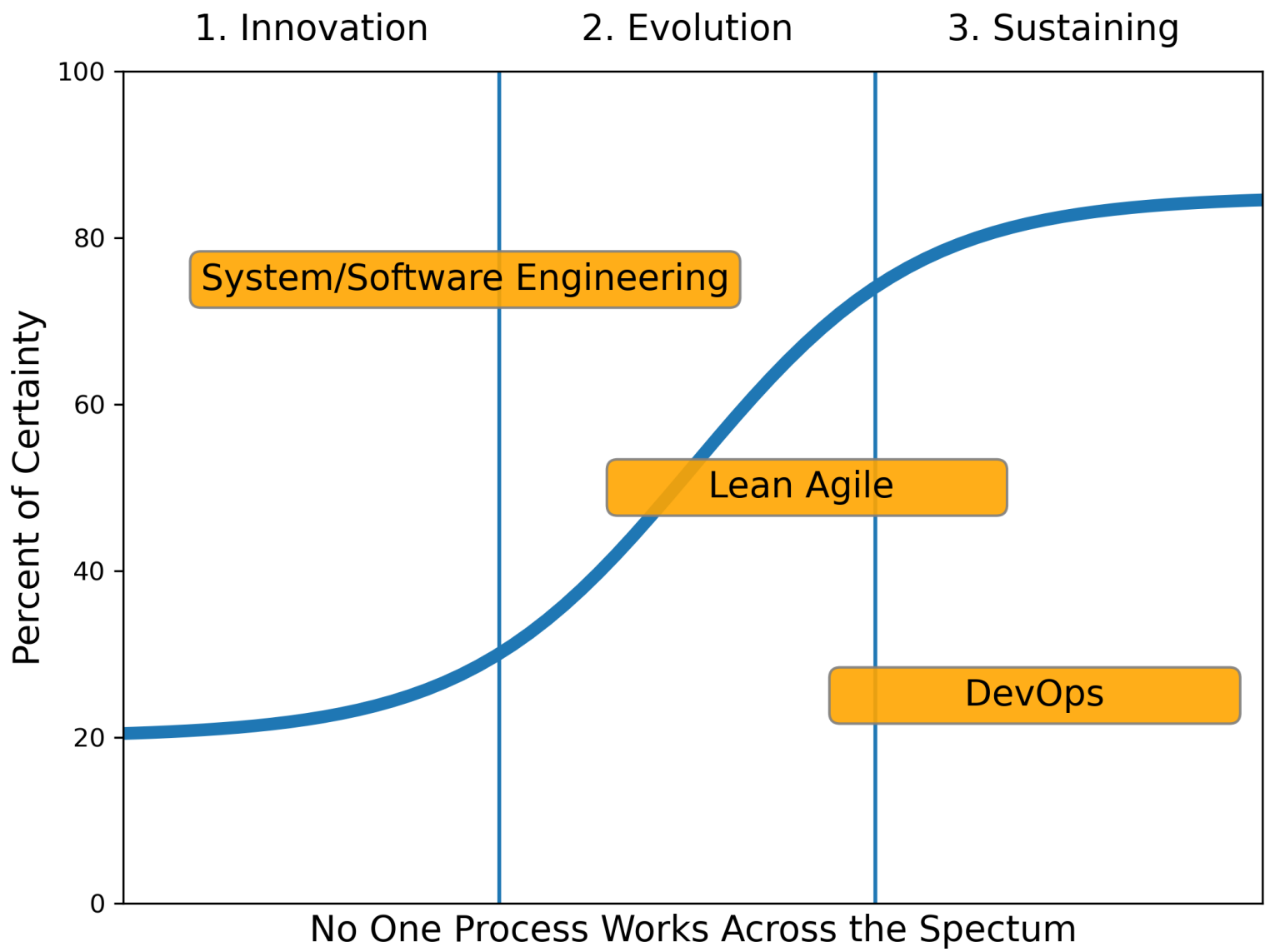

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