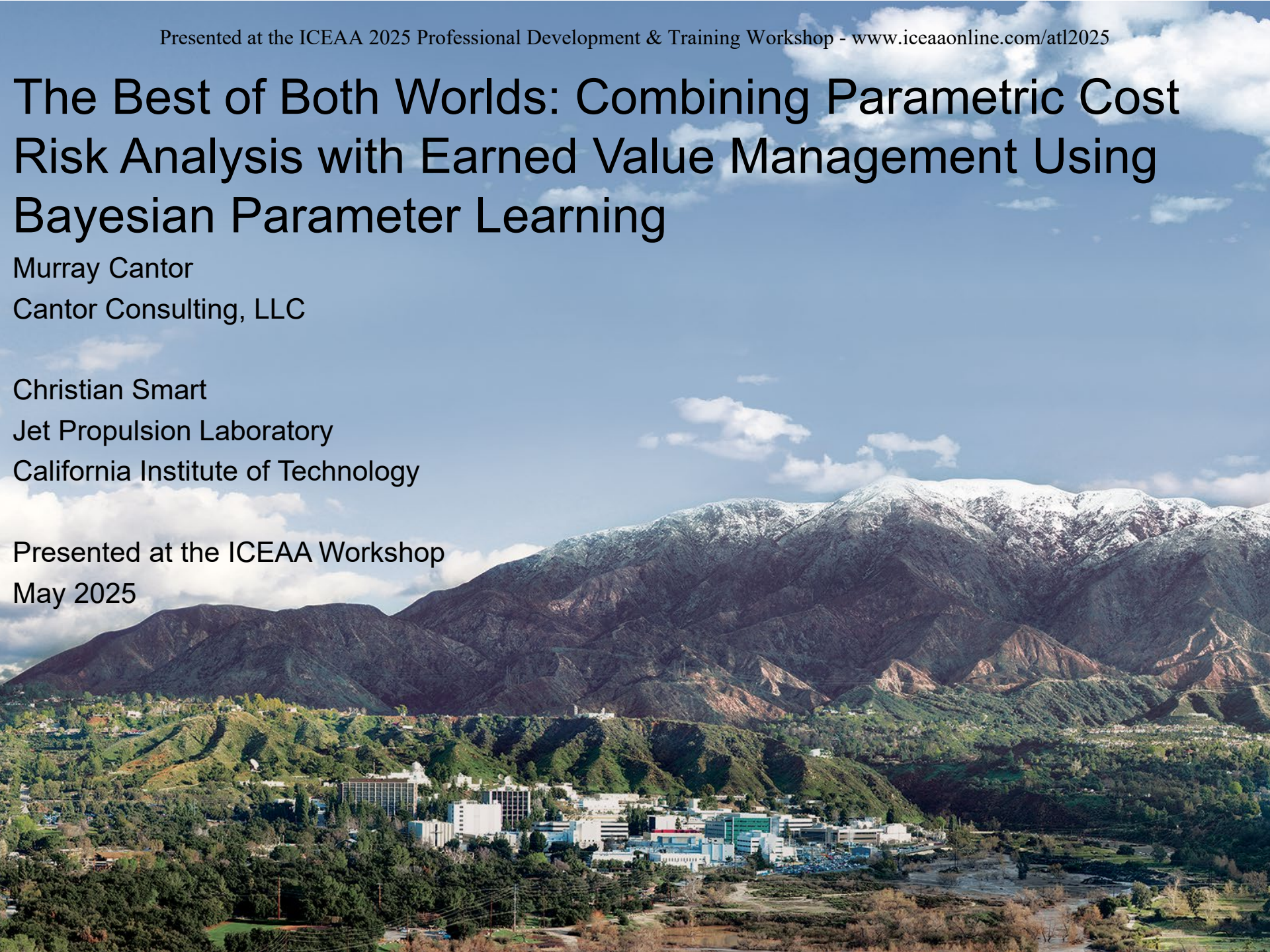


The Best of Both Worlds: Combining Parametric Cost Risk Analysis with Earned Value Management Using Bayesian Parameter Learning

Murray Cantor
Cantor Consulting, LLC

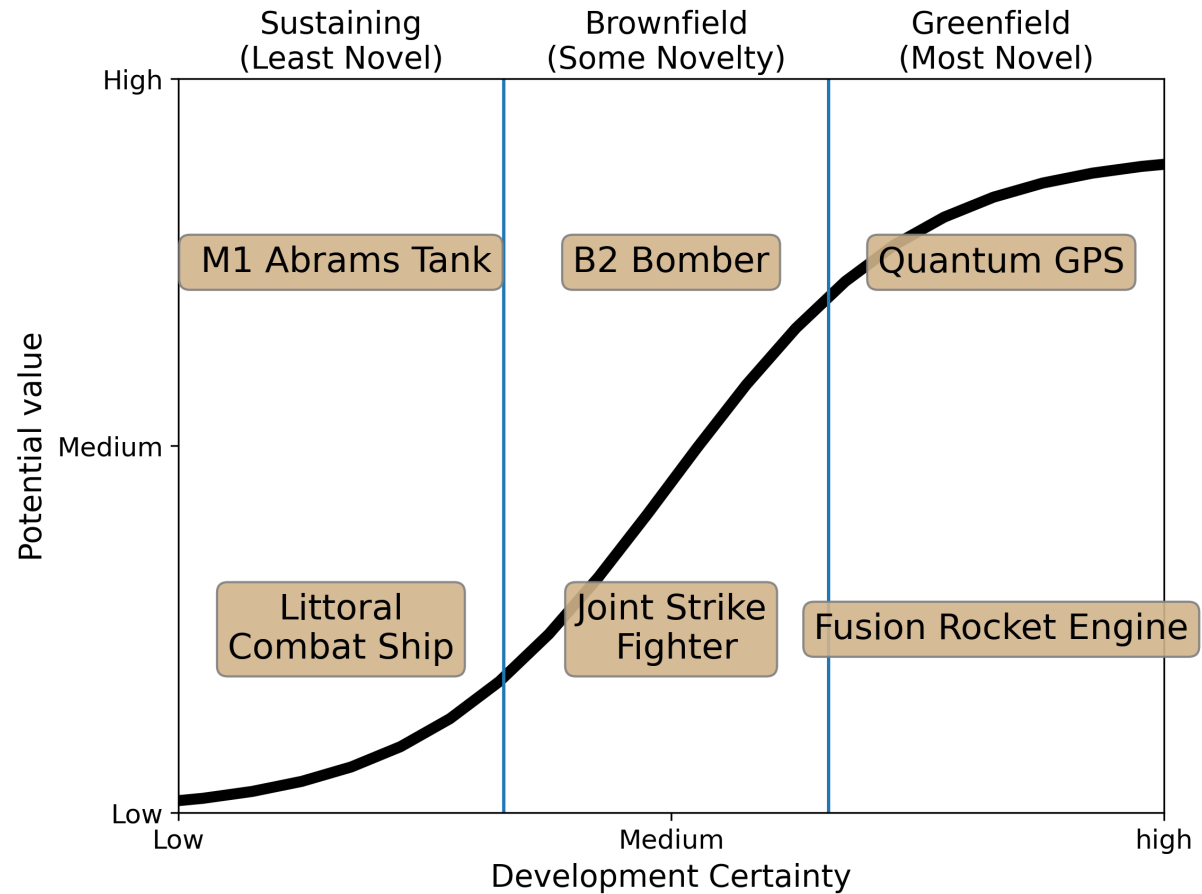
Christian Smart
Jet Propulsion Laboratory
California Institute of Technology

Presented at the ICEAA Workshop
May 2025



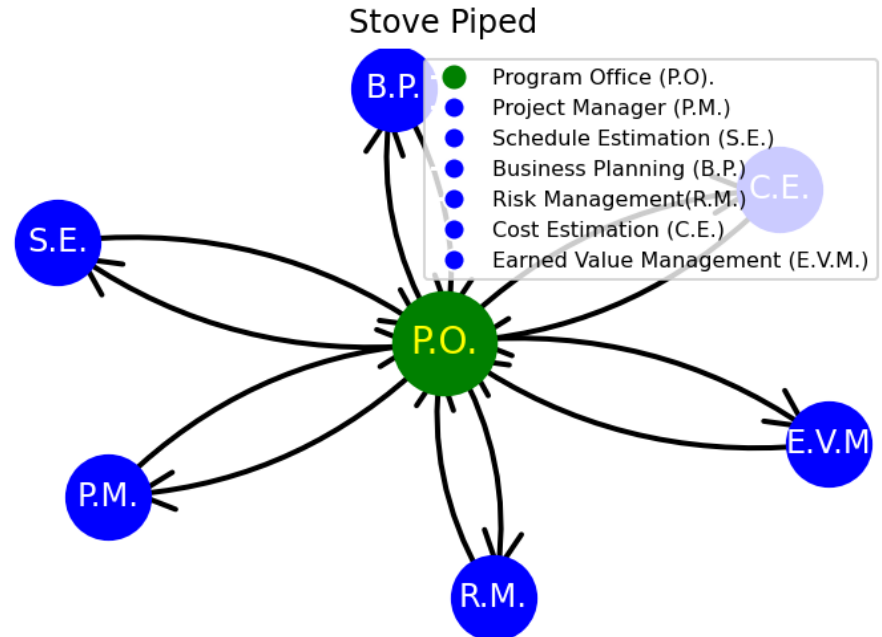
Innovation Fuels Uncertainty, Origin of Risk

- Applies to novel projects
- Uncertainty due (partially) to incomplete knowledge
- Aerospace projects are often require technology development and take many years to develop



The Problem

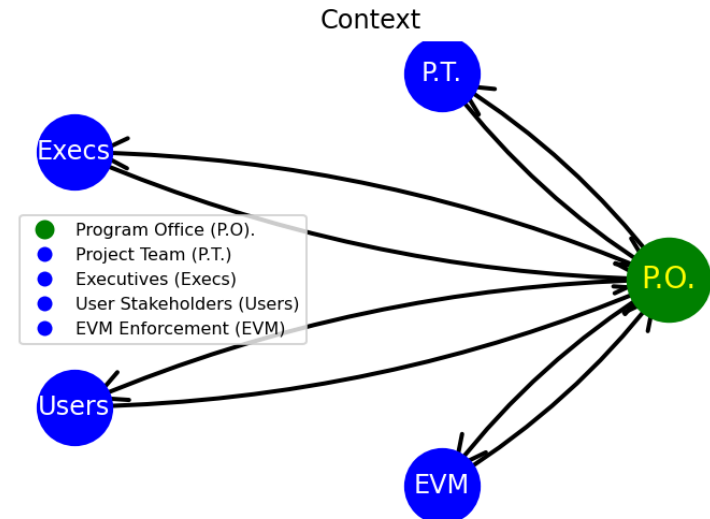
- Stove pipes
 - Project Management
 - Business Planning
 - Cost Estimating
 - Schedule Estimation
 - Earned Value Management
 - Risk Management
- Lack of Objective, rigorous, agreed-upon framework
 - Different assumptions
 - Different ad-hoc methods
- Collaboration may be
 - Inadequate
 - Hub and spoke



Coordinated perspective on uncertainty and risk is needed.

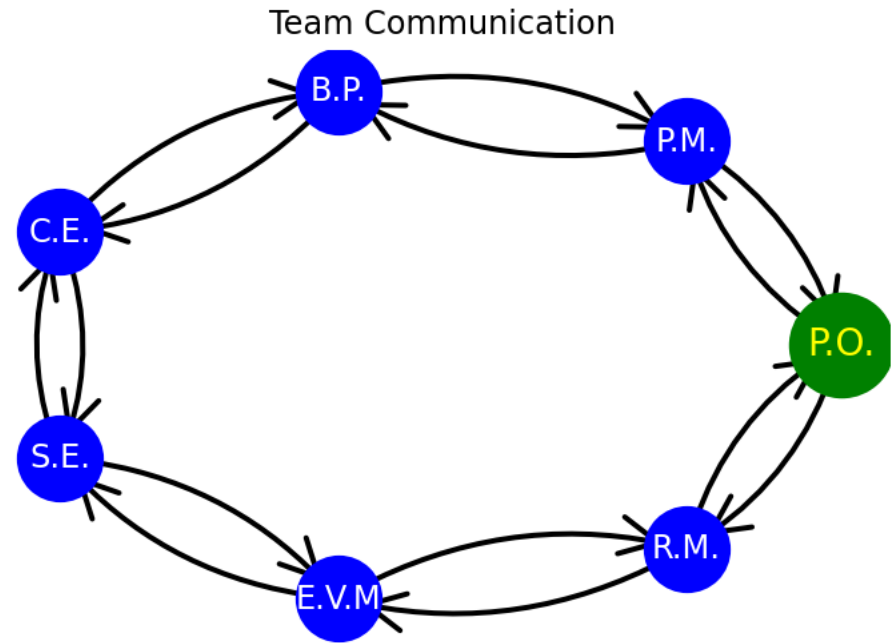
EVM and the Communication of Uncertainty to Stakeholders

- Needed to address EVM, **CMA** enforcement phenomenon as well as other stakeholders
- Current techniques are ad hoc with to truly manage uncertainty
- Need more rigorous, *probabilistic* techniques



Management of Uncertainty is Necessary for Collaboration

- Report EVM
- Set and manage stakeholder expectations
 - Schedule
 - Cost
- Meet firm deadlines
 - Meet launch windows, release dates
 - Needed for specific events
- Prioritize scope versus schedule



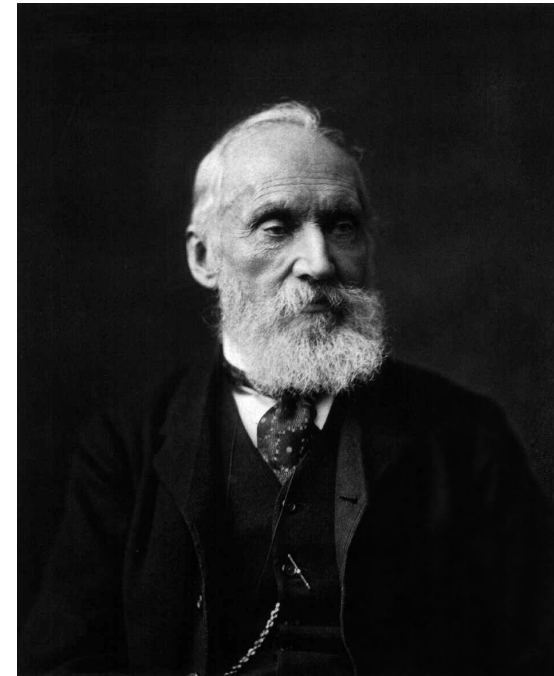
Risk Management Enable Success

Required Breaking Down Stovepipes

- 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., cost per kill)
- One can take action to improve the odds of meeting cost and schedule goals.

"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)

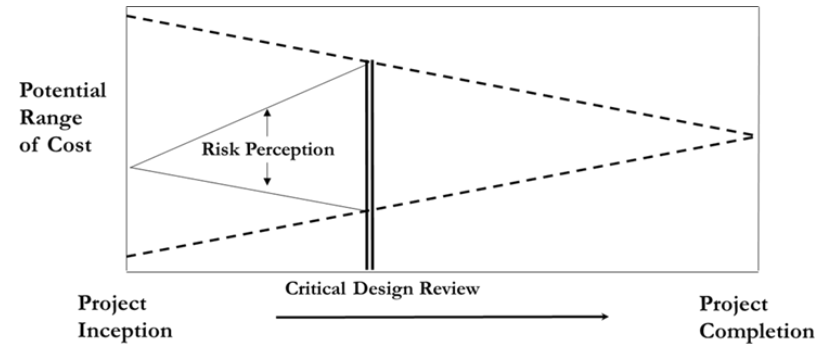


We present a method for measuring the uncertainty in the cost and schedule as it proceeds.

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



Opportunity for Improvement

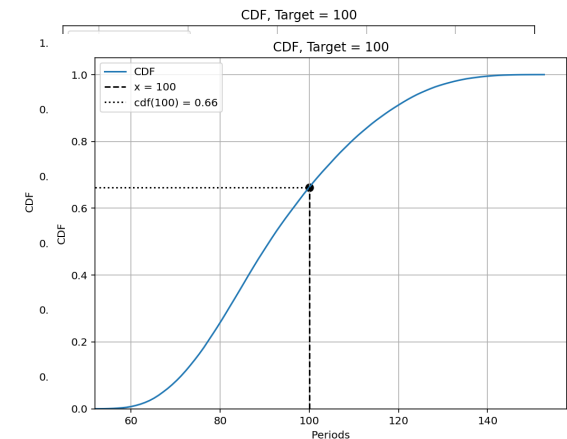
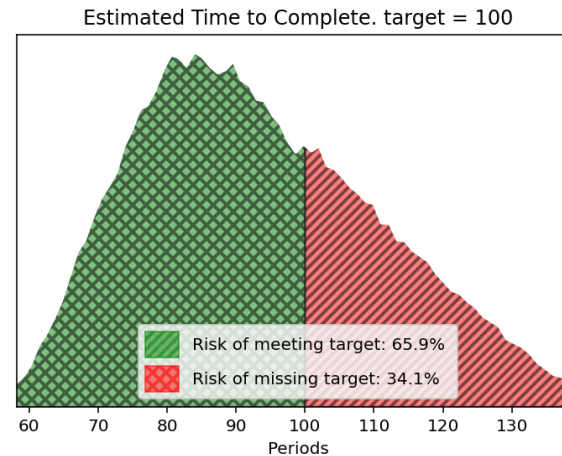
- Emergence of Bayesian techniques in Machine Learning
 - Integrates expert opinion with actual experience
 - Returns probability curves to enable measurement of uncertainty.
 - Can handle small data of PM actuals
- Adequate compute environment
 - Software
 - Python, cython, ...
 - Pandas, Numpy, Scikit, ...
- Hardware
 - Cloud
 - Performance of latest chips

Core Algorithm

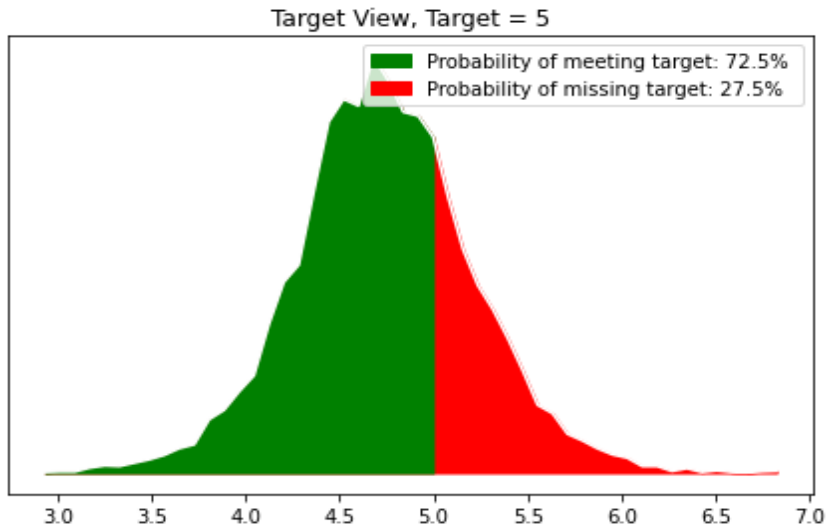
- Elicit prior estimate of time or cost to complete:
 - (*best case, expected case, worse case*)
 - Empirical from estimation tools
- Treat estimates as velocities at completion
 - $V_{cost} = \frac{Actual\ Cost}{\% \ complete}$
 - $V_{duration} = \frac{Duration}{\% \ complete}$
- Update velocities using quotient of tracking data as observations for Bayes Theorem to get pdfs
- Use these pdfs and Monte Carlo simulation to estimate the remaining times and costs to the % remaining

A Proposed Solution

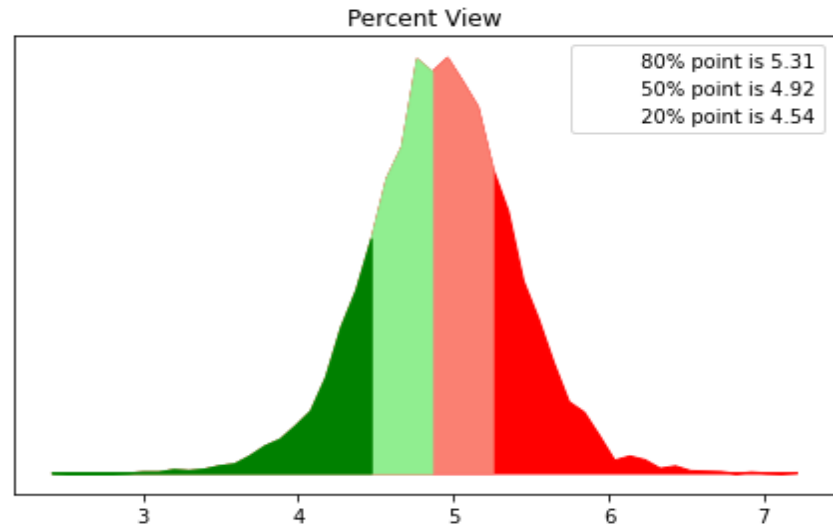
- A combination of risk analysis and EVM
- includes the conditional probability of risk events
- Progress is the reduction of risk throughout the lifecycle.
- It uses data you already (should) have:
 - Initial estimates
 - SME – Deterministic or 3-point estimates
 - Estimation tools that return probability or ‘S-curves’
 - Historical analogies
 - Tracking actuals of durations and costs
 - Required for EVM
 - Use ground truth
 - Ratios give velocities
- Mathematically sound velocity calculations
 - Velocities are key.
 - Uses Bayes theorem to update the initials with the actuals
 - Whitepaper available



Two Ways to Visualize Uncertainty



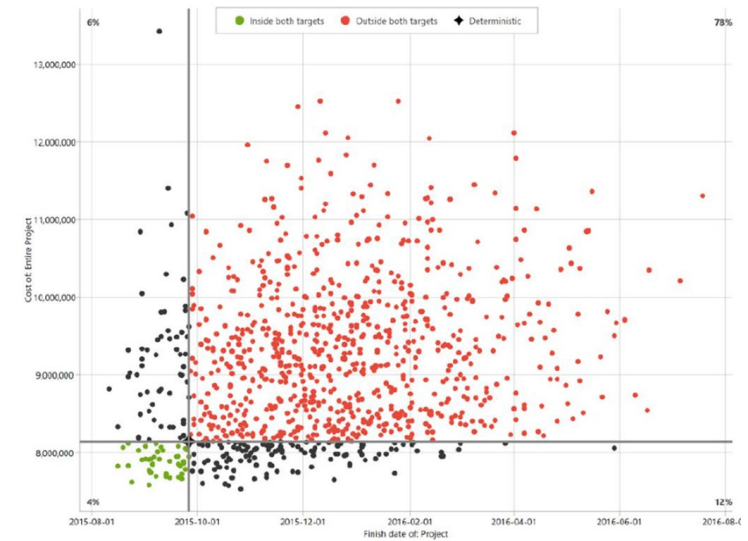
Likelihood of meeting or beating the target



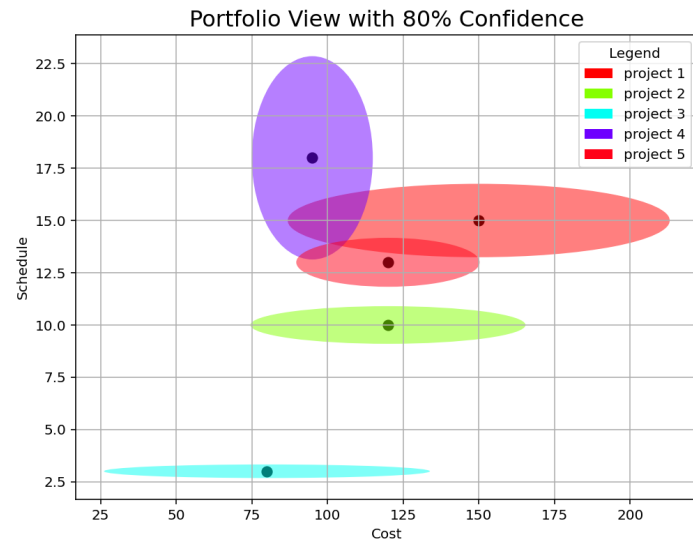
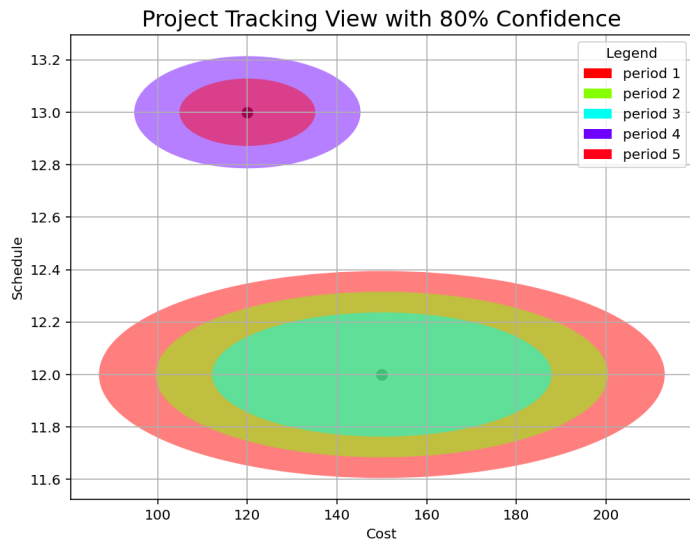
How much will you miss or beat the target

Joint Cost and Schedule Prior Scatterplot

- Often based on:
 - Previous Team History
 - Parametrics
- Often return probabilities
- Are not updated with actual team performances

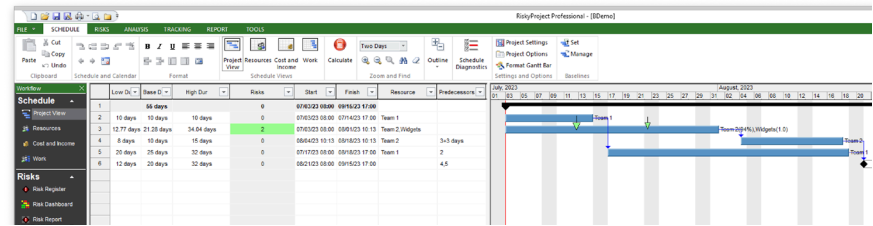


Cost and Schedule Graphs

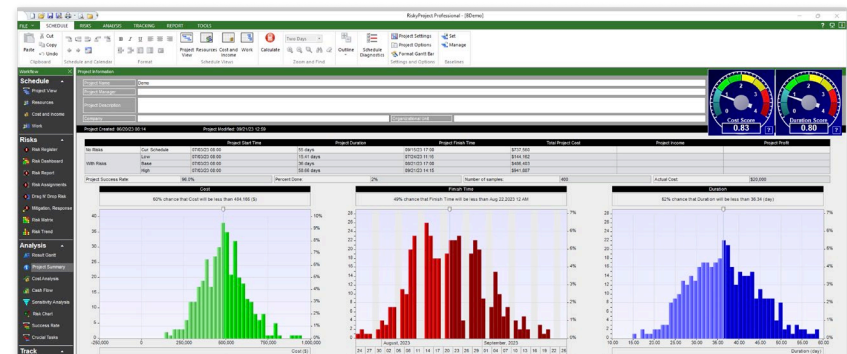


Tools Are Emerging

- We have developed a cost and schedule velocity learning algorithm
- Tools are becoming available
- Intaver RiskyProject Predictor Module
- Estimated Time to Complete (ETC) is very soon available from Intaver
- Working together to include all EVM
- Combines risk management and Bayesian risk analysis
- Custom tools are also available from Cantor Consulting

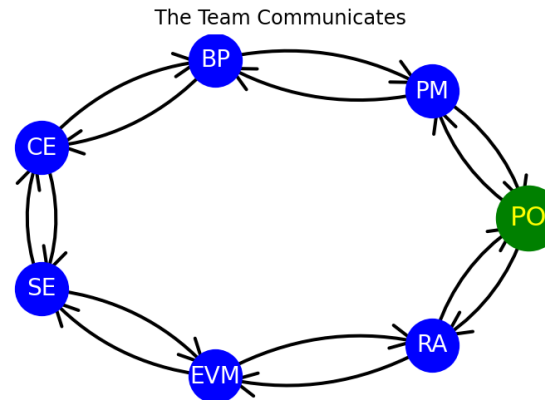
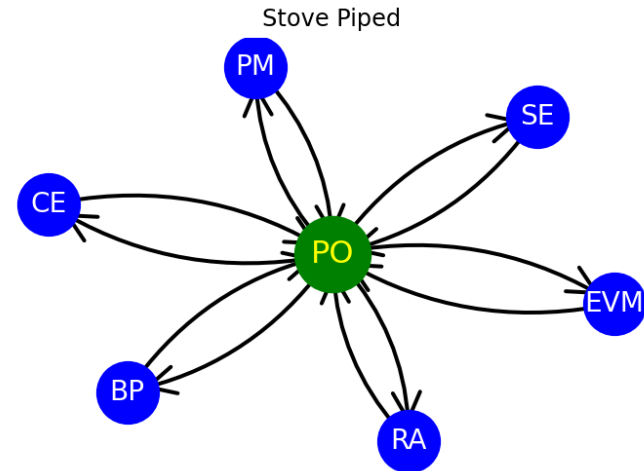


Task Name	Low Dur	Base Dur	High Dur	Risks
Phase 1		88 days		0
Task 1	10 days	10 days	10 days	0
Task 2	12.77 days	21.28 days	34.04 days	2
Task 3	8 days	10 days	15 days	0
Task 5	20 days	25 days	32 days	0
End phase 1	12 days	20 days	32 days	0



What a Solution Entails

- Cultural change
 - More transparency
 - Better communication
- Revised management processes
 - Integrating stovepipes
 - Revise decision rights (aka RACI)



Key Points

- Analogy – cruise missile rather than ballistic missile
 - Steers to target during flight
- Progress is measured by the change in uncertainty during a project's development
- Avoids the green, green, red, phenomenon
 - Provides warnings in time to take action
- Provides better estimates than commonly used agile velocity measures
 - Rigorous mathematical approach



Thank you for your time and attention

Questions??

References

- Cantor, M. (2023). *Bayesian Parameter Learning V2*. Retrieved from LinkedIn.com: https://www.linkedin.com/posts/murraycantor_intro-to-bayesian-parameter-learning-v2-activity-7117523872907677698-4Dry?utm_source=share&utm_medium=member_desktop
- Cantor, M and Smart C (2024). *The Best of Both Worlds: Combining Parametric Cost Risk Analysis with Earned Value Management Using Bayesian Parameter Learning*.
- Smart, C. (2020). *Solving for Project Risk Management: Understanding the Critical Role of Uncertainty in Project Management*. McGraw Hill.