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STEVENS
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Stevens Institute of Technology
&
Systems Engineering Research Center (SERC)

Modeling an Acquisition Decision-Making Process for the FAA NextGen Systems of Systems

Presented to: NDIA 2012

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Outline

- Part 1:
  - What is the Federal Aviation Administration's (FAA) NextGen
  - Who are the stakeholders?
- Part 2:
  - Problem using FAA NextGen System of Systems (SoS) Terminology
- Part 3:
  - Objective, conceptual approach, & expected analysis outputs
  - Bayesian networks concept and visualizing risks
  - Scenario for using the Analysis and Modeling Framework for Asynchronous Integration and Deployment (AMF4AID)
- Conclusions
- Acknowledgment

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Part 1:
What is NextGen and who are the Stakeholders?

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What is the FAA NextGen?

Image credit: NextGen Far-Term (2025), To-Be Enterprise-Level Architecture High-level Operational Concept Graphic (OV-1) Version 1.0, January 29, 2010

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NextGen Vision of Integrated Framework of SoS Operations

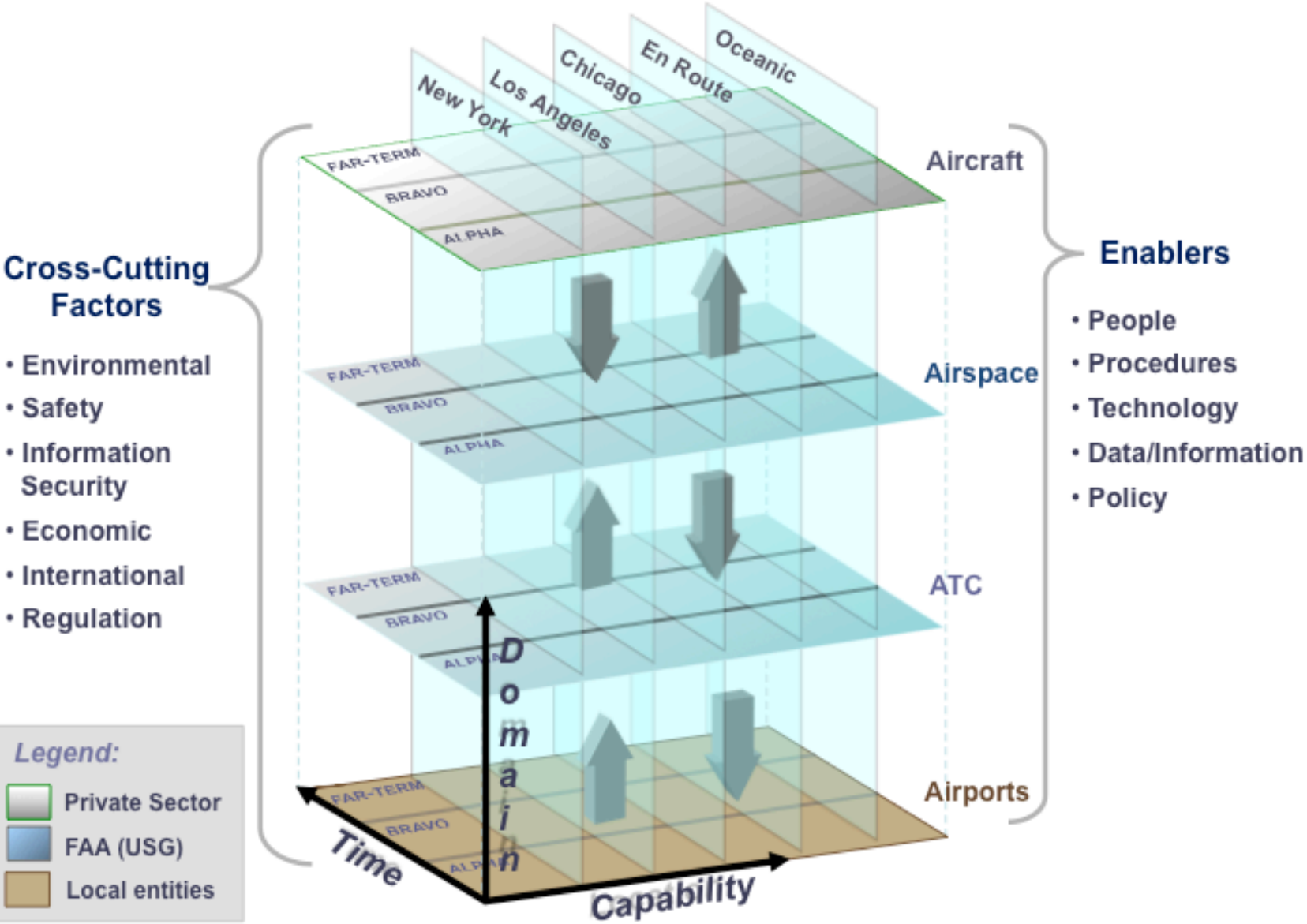

Image credit: Ron Stroup,
Chief Systems Engineer for Air-Ground Integration

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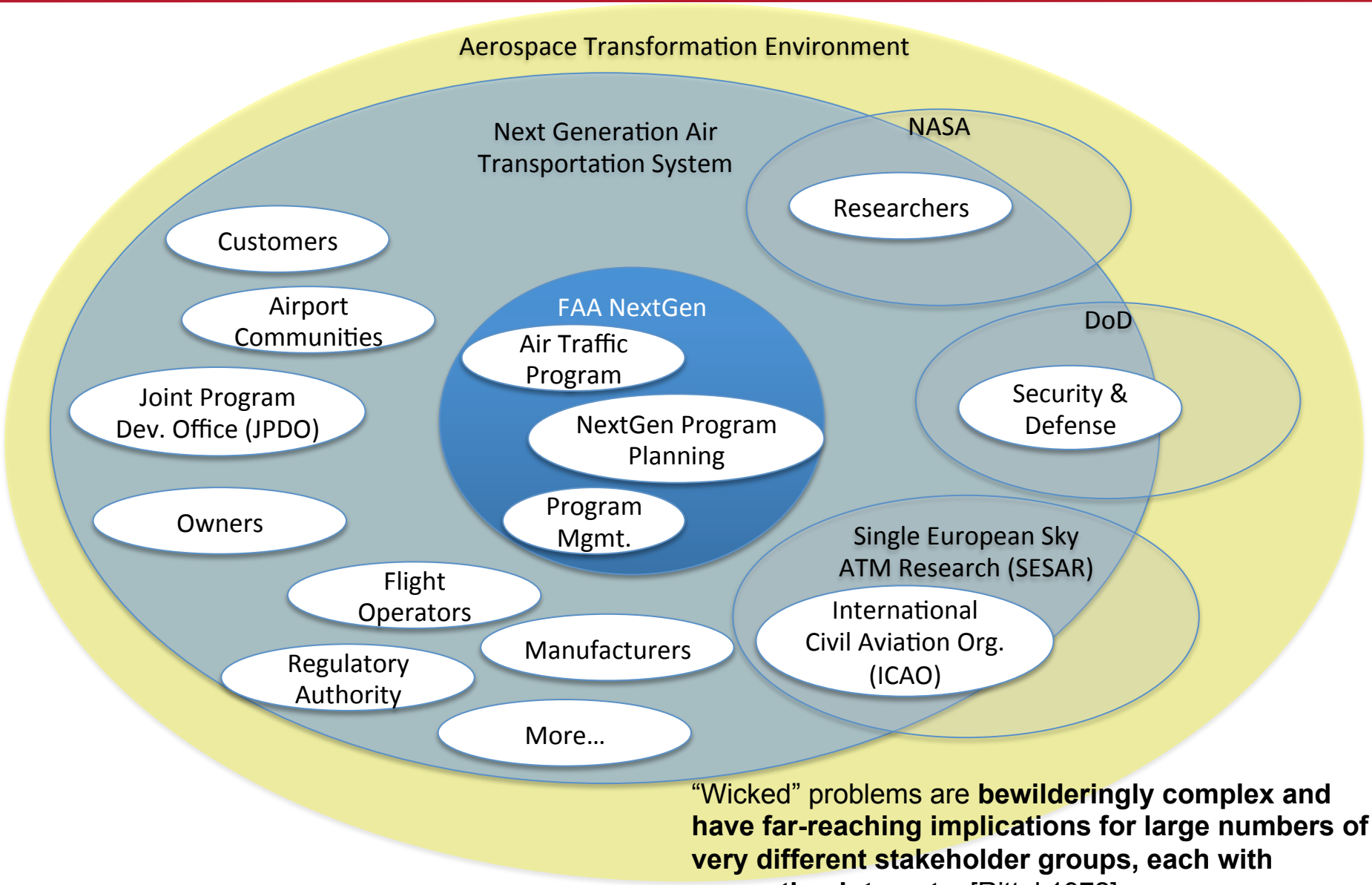
NextGen Has a Diverse Set of Stakeholders that Contribute to and Impact Decisions



"Wicked" problems are **bewilderingly complex and have far-reaching implications for large numbers of very different stakeholder groups, each with competing interests**. [Rittel 1972]

Inspired by: Assessment Of The Faa Nextgen Acquisition Process & Development Of A Progress Metric Framework For Portfolio Management, Patrice Kone, 2012

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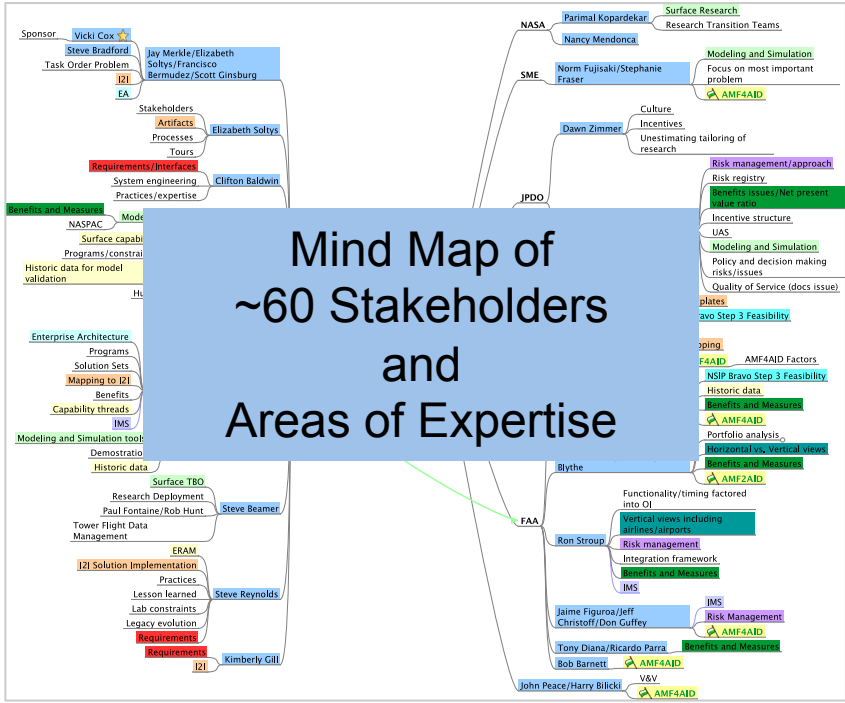
We Talked to Many Stakeholders about Various Aspects of the System of System (SoS)

- We started with FAA's Assistant Administrator for NextGen, Vicki Cox (our research sponsor)

- After talking with more than 60 success-critical stakeholders, who were very open about the challenges, we found out that:
  - All component dependencies are not systematically identified
  - All interface dependencies are not formally tracked (e.g., using databases)
  - Tradeoff impacts difficult to assess
  - People can only roughly estimate impact of interdependencies between component functionality
  - Difficulty continually challenges those responsible for planning, developing, and deploying capabilities



Part 2:
Problem
using
FAA NextGen SoS Terminology

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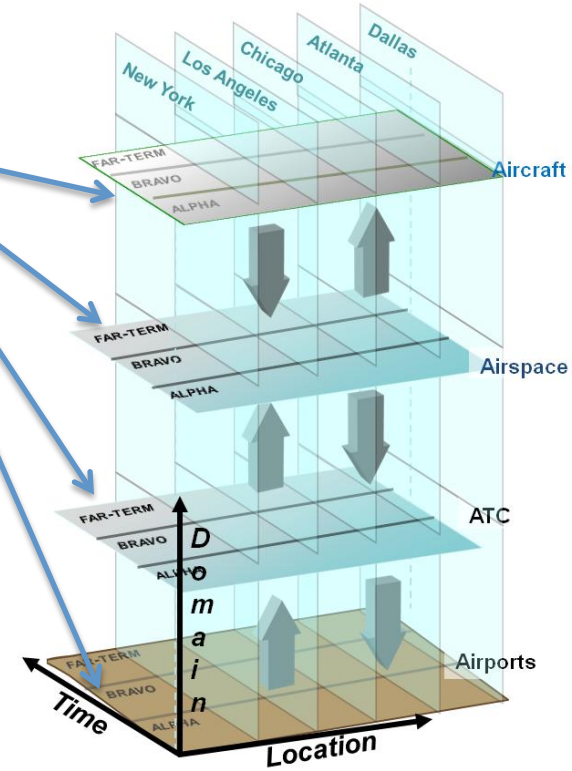
FAA NextGen Rolls Out Capabilities to SoS

- Capabilities cut across programs, domains, and time

Solution Sets
Trajectory Based Operations (TBO)
High Density Arrivals/Departures (HD)
Flexible Terminals and Airports (FLEX)
Collaborative ATM (CATM)
Reduce Weather Impact (RWI)
System Network Facilities (FAC)
Safety, Security and Environment (SSE)

Capabilities

Transformational Programs
Automatic Dependent Surveillance Broadcast (ADS-B)
System Wide Information Management (SWIM)
Data Communications
NextGen Network Enabled Weather (NNEW)
NAS Voice Switch (NVS)
Collaborative Air Traffic Management Technologies (CATM-T)



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Example Capability Mapping to Programs and Decision Points

Sample OI/Capability to Sub-capability to Infrastructure Roadmaps Mapping

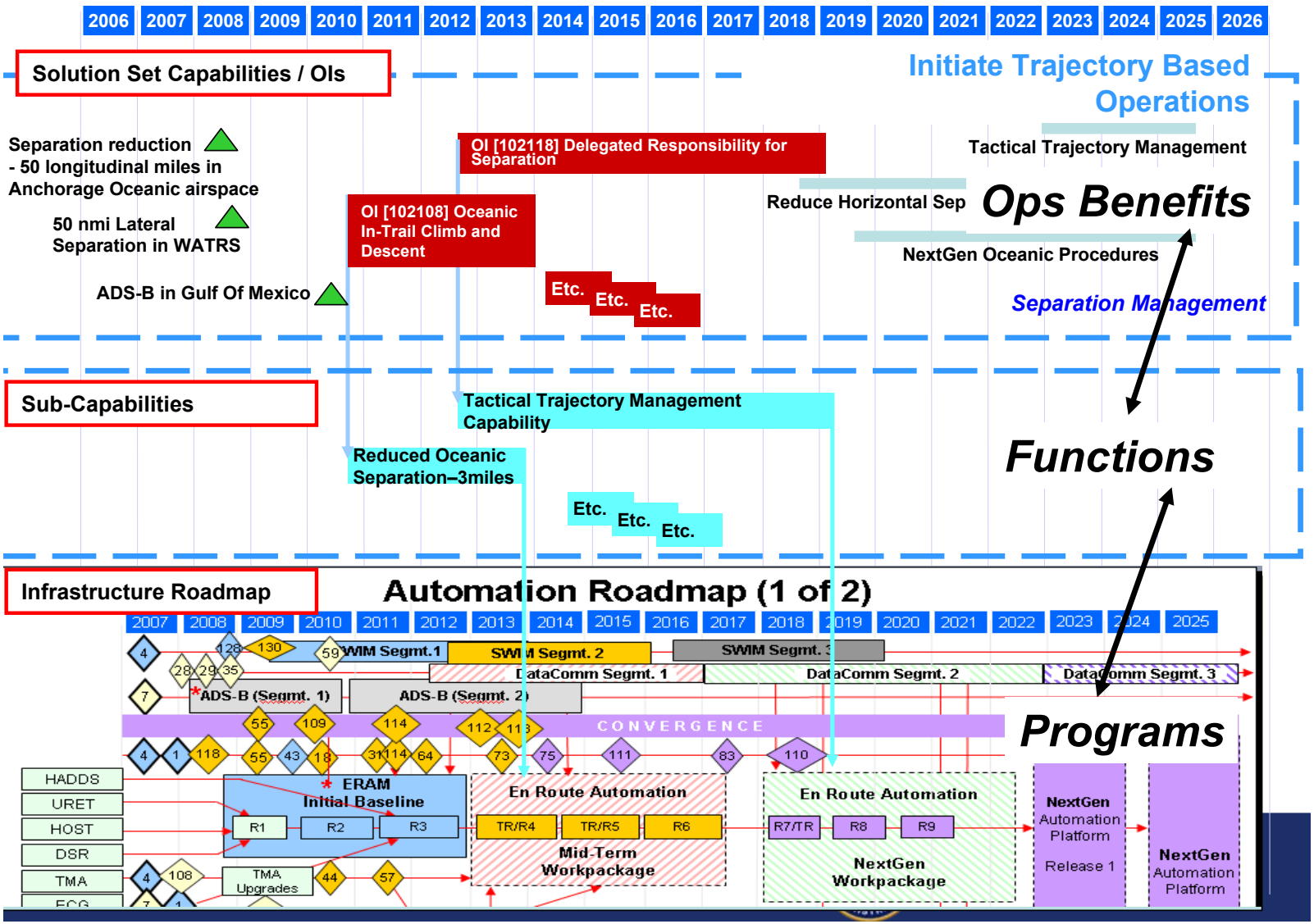

Image credit: FAA NAS Enterprise Architecture Federal Aviation Administration, Jesse Wijntjes / NAS Chief Architect April 28, 2010

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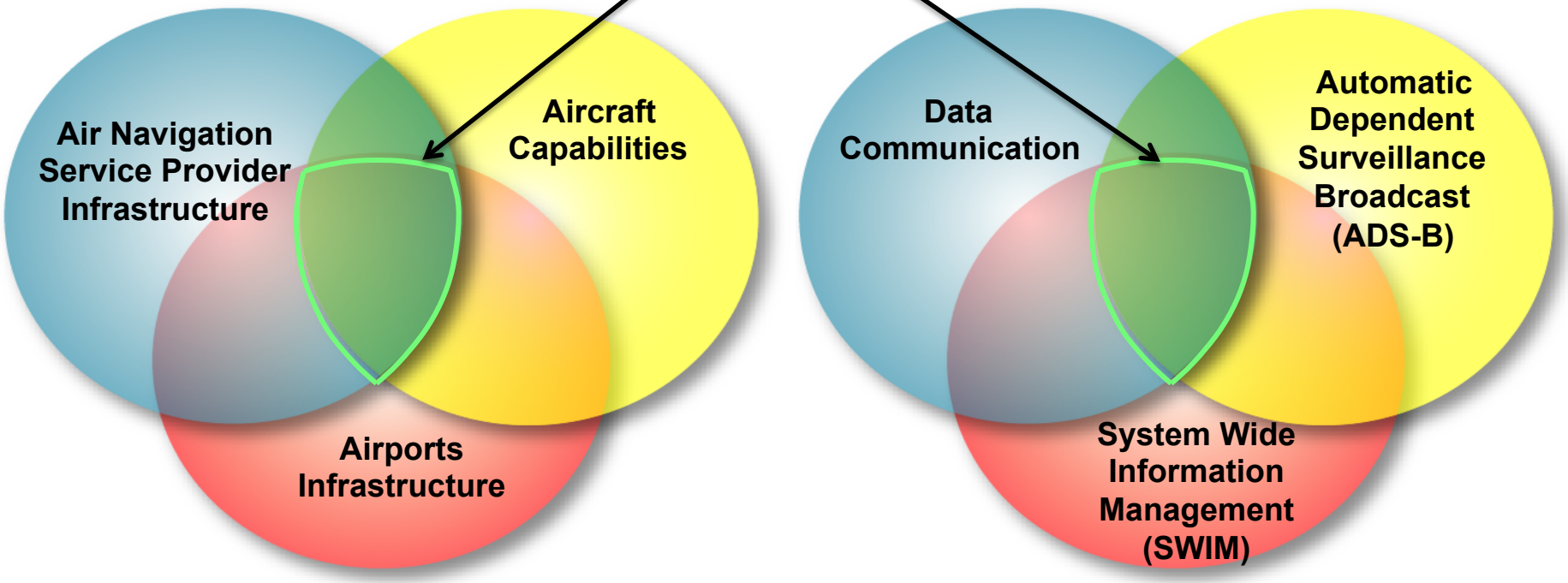
To Realize Benefits the Transformation Requires Integration Across Domains

What's so Challenging?

Success *only* occurs here.



Example of Program Dependencies for Capability

Inspired by Ron Stroup,
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Part 3:
Objective,
Conceptual Approach,
Expected Analysis Outputs
&
Analysis and Modeling Framework for Asynchronous Integration and Deployment (AMF4AID)

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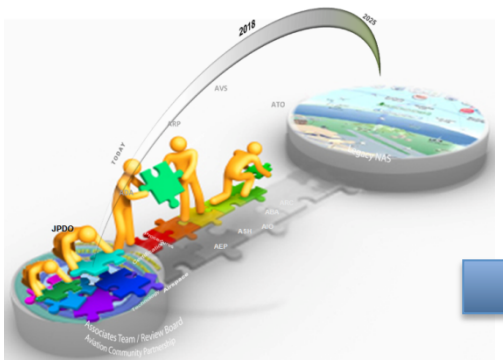
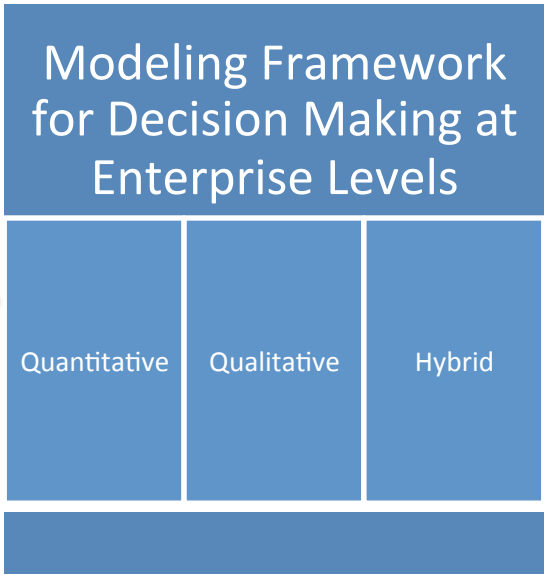
Objective Statement from Kickoff Meeting

- **Develop a modeling and analysis framework** to enable a **process for managing decision-making** that occurs when capabilities must be integrated, deployed and acquired asynchronously
  - Analysis and Modeling Framework for Asynchronous Integration and Deployment (AMF4AID)
  - **Predictive Model for Estimating Cost, Schedule, Benefits, with Visualizations of Probabilistic Risk to aid in decision making**



Which capability?



- **Cost, Schedule, & Benefit predictions**
- **Risk calculations**
- **Factor impacts on practices**
- **Support Ideas-to-In Service (I2I) process**

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FAA Problem Statement Summary

- NextGen is being implemented through a time-phased series of Operational Improvements (OI), each of which is broken down into a series of OI Increments (aka Functions)
- Acquisition of each Function is defined in a "scenario" that has a predicted cost, schedule, benefit, and risk
- In practice, scenarios don't play out as originally planned
  - E.g., technologies mature more slowly than expected
- Scenarios often have multiple dependencies
  - It is often difficult to understand the relationships between scenarios
  - Even more difficult to understand implications of changing one or more scenarios
- This research will develop a model that helps decision makers better understand the relationships between scenarios and to better predict the effect of changing them
  - This should aid in their selection of the best series of scenarios to implement capabilities

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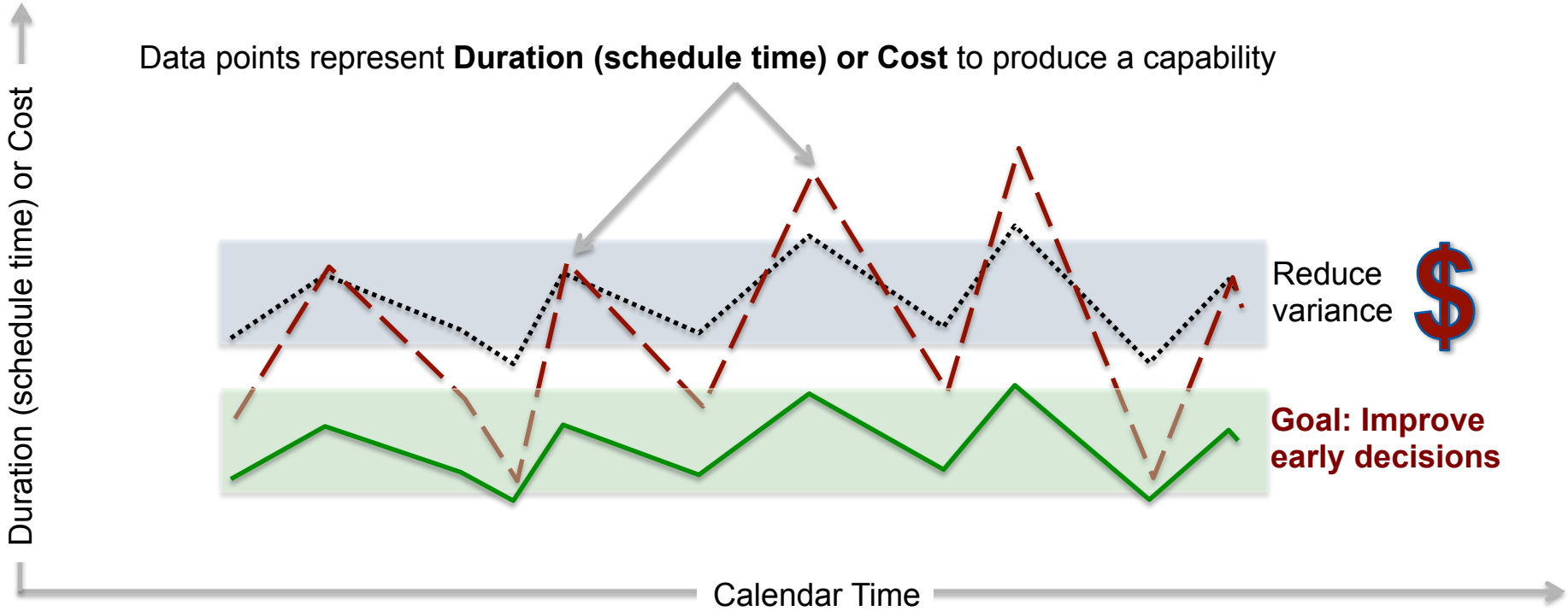
Conceptual Objective for our Research and Model

- Need to deploy capabilities within cost/schedule limits
- Complexity and scale of problems often negatively impacts meeting targets
- Model allows decision maker to improve prediction of cost and schedule
- Goal: allow decision makers to better understand alternative for desired outcome earlier



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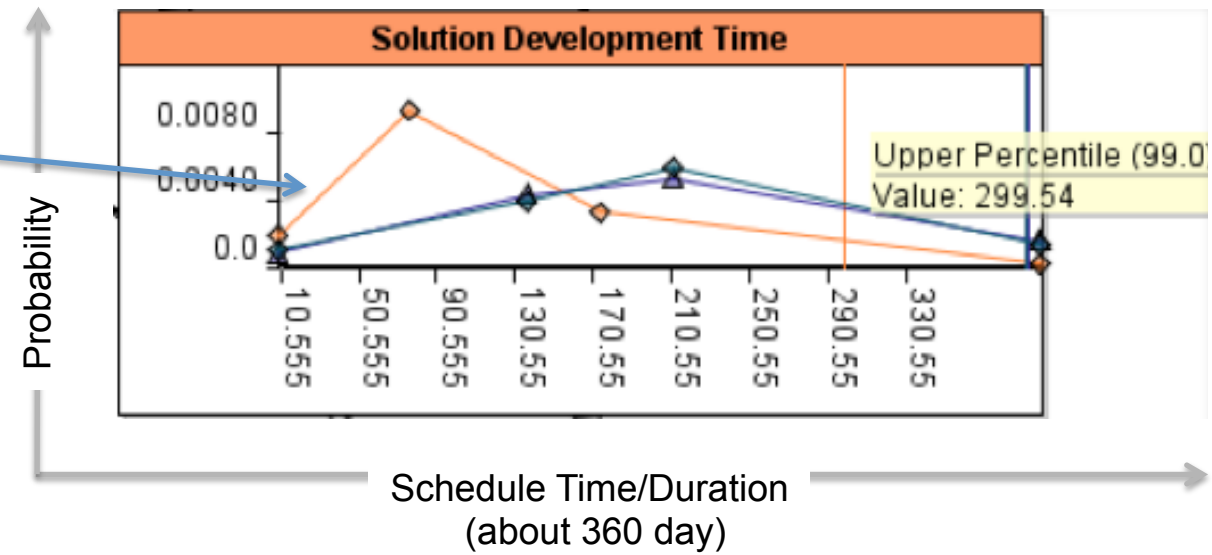
Framework Predicts Risk using Bayesian Networks That Combine Quantitative and Qualitative Data

- Bayesian networks combine quantitative with qualitative expert judgment to capture and leverage causal relationships about **"Peoples' internal knowledge that is not captured externally or formally"**
- Tooling for framework provides probabilistic representation of cost, schedule and benefit risks that enable stakeholders to make better decisions

The probability of completing the function (associated with orange line) in fewer days is better than for blue or purple (less risk)



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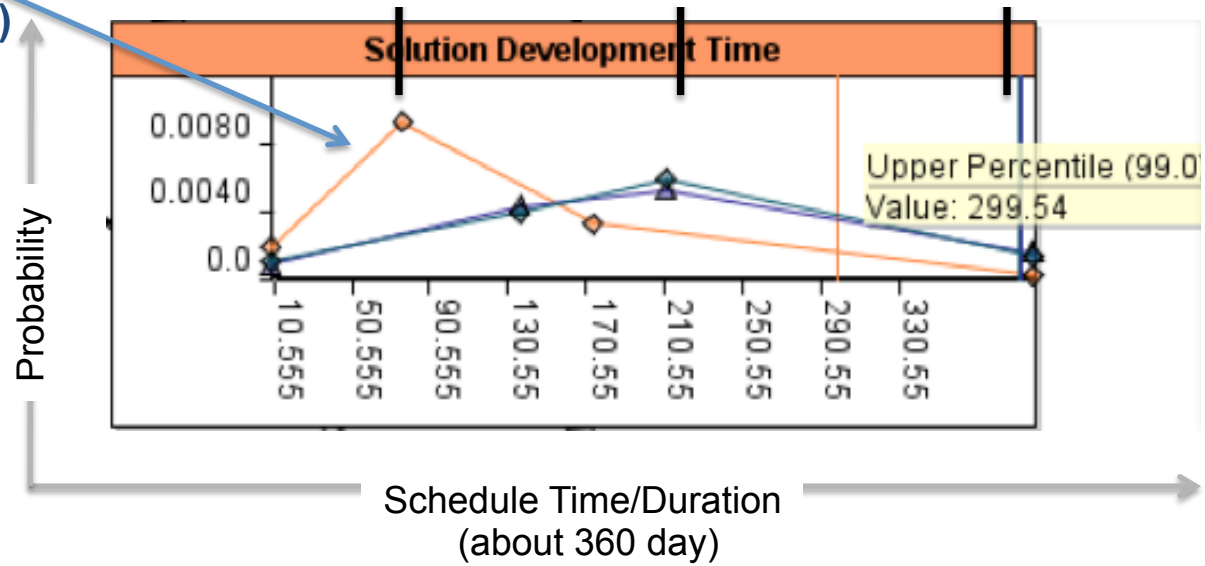
Map the Probabilistic Representation of Risk based on Program Factors to Risk Matrix

Risk Matrix							
Likelihood	Near Certainty	E					
	Highly Likely	D					
	Likely	C					
	Low Likelihood	B					
	Not Likely	A					
			1	2	3	4	5
			Very Low	Low	Moderate	High	Very High
			Consequence				

Different Points Along the x-Axis Map to Risk Values Associated with Meeting Schedule

The probability of completing the function (associated with orange line) in fewer days is better than for blue or purple (less risk)



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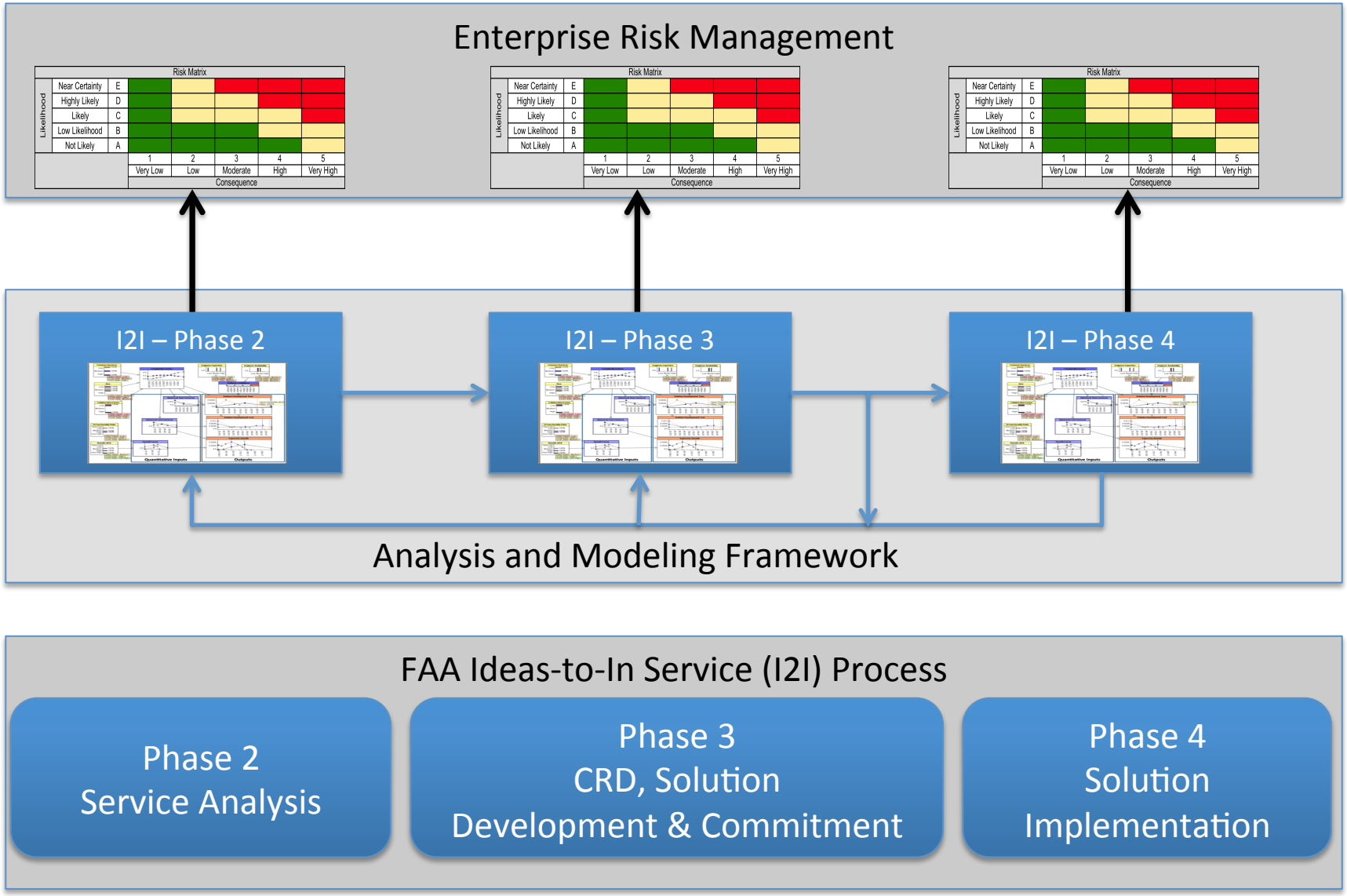
Researching How Models Align with I2I Process to Calculate Various Aspects of Risk



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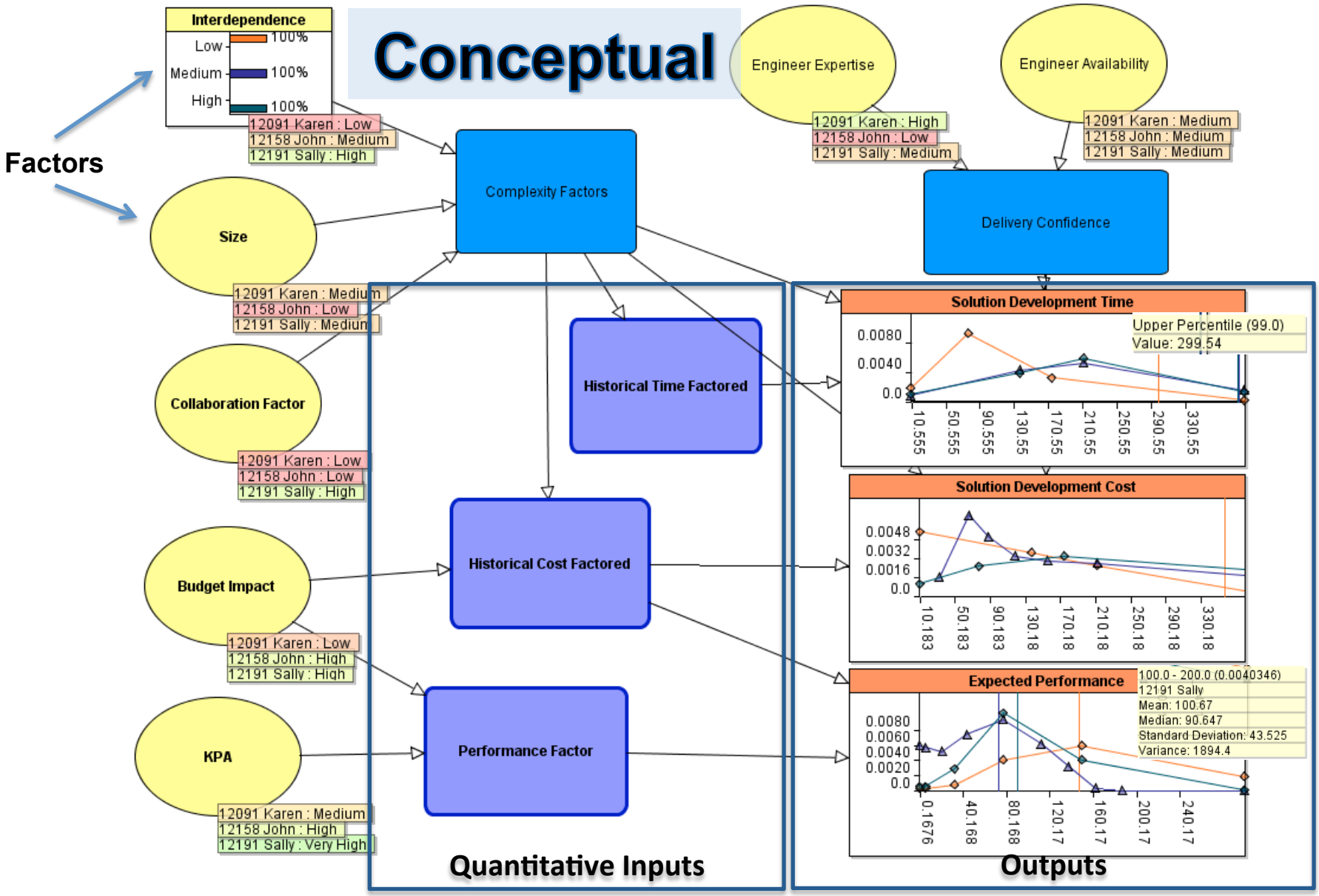
Conceptual Usage Scenario Illustrating Cost, Schedule, Benefit, and Risk Tradeoffs



Conclusions

- NextGen is a complex System of Systems and rolling out capabilities is challenging due to many factors and complex interdependencies and diverse set of stakeholders
- We are developing a modeling and analysis framework to enable a **process for managing decision-making**
- Framework helps stakeholders understand cost, schedule, benefits, and risk tradeoffs
- Approach will improve the accuracy of schedule and cost predictions (and reduce the variance)
- Bayesian networks combine quantitative with qualitative expert judgment to capture and leverage causal relationships about **"Peoples' internal knowledge that is not captured externally or formally"**

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Acknowledgment

- We wish to acknowledge the great support of the FAA sponsors and stakeholders, including stakeholders from NASA, JPDO and other industry partners that have been very helpful and open about the challenges of this complex problem.

- We also want to thank Dr. Bill Kaliardos from the FAA who provided excellent comments that helped us improve this presentation especially for people not familiar with the FAA.

Thank You

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Scenario for Conceptual Bayesian Network

For example, consider the following conceptual scenario. There are three programs competing for funding in an acquisition cycle (yearly). There are three program managers, Karen, John and Sally (hypothetical).

1) For each of the qualitative factors, Karen, John, and Sally assign subjective values to the factors.

The capability interdependencies (Interdependence) for Karen's program is Low, John's is Medium, and Sally's is High. This means for example that Karen's program is not very dependent on the completion of other systems or components in order to complete the integration and deployment of the program, which might be developed by another program, and therefore the risk is lower for this program than for John's and Sally's program.

The Collaboration Factor for Karen and John's program is Low, and High for Sally's program. This factor reflects that Sally must coordinate with other programs in order for the functionality of her program to be realized, and therefore this increases the risk for completing the integration and deployment of Sally's program.

The Engineering Expertise and Engineering Availability factors can represents both the Expertise and Availability of the contractors that will develop a particular program. Availability can reflect both the resource availability and capacity (e.g., the contractor is already developing a large software project this year, which might mean their availability for more development is Low).

2) The qualitative factors are combined with quantitative historical factors to give a probabilistic representation of cost, schedule and performance risk. For example:

Based on historical schedule data (in days), assuming a normal (or Gaussian) distribution (which may not apply), the mean number of days to complete Karen's program is about 125 days, with a near 99% belief that it will be completed in 299 days (highlighted vertical Orange Line), while the mean is about 200 days for John's and Karen's programs, but to achieve 99% confidence it could take as long as 400 days. Given a yearly acquisition cycle, the lower risk program, based on schedule, is Karen's program.

Based on historical cost data (using hypothetical $K dollars), the mean cost to complete the program is: Karen ($118K), John ($178K), and Sally ($206K).

Based on projected performance (no particular units assumed in this example, because performance value could be exponential), the Key Performance Areas (KPA) for Sally's program is Very High, John's is High and Karen's is Low. There are other possible measures with causal relationships to performance, such as budget (Budget Impacts) required to complete the program, and the resulting relative performance for John's program is 71, Sally's is about 100, and Karen's is about 150 (i.e., benefit to the DoD mission).

3) Based on this analysis, there are several possible conclusions, but a likely choice is:

Karen's program delivers the most performance benefit relative to the schedule risk, with only slightly higher cost than John's program

4) If the PMs or other stakeholders do not agree to the risk-based representation of the cost, schedule, and performance risk tradeoffs (e.g., the General insists that John's or Sally's program be deployed), then the stakeholders have the ability to look at modifying program decisions associated with the factors. A "what if" analysis could be performed while the stakeholders are together.

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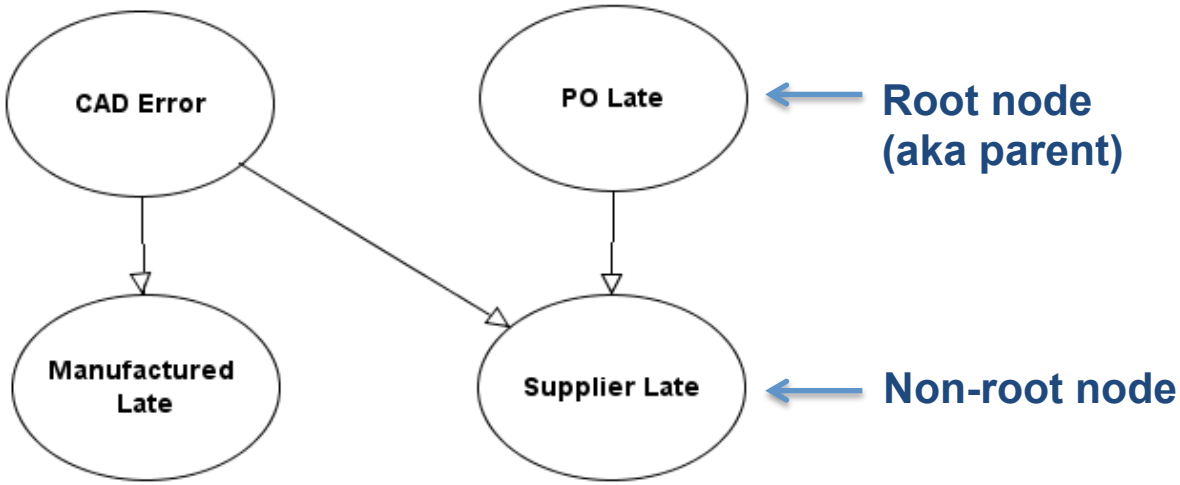
What is a Bayesian Network?

- Bayesian Networks (aka Bayesian Belief Networks) describe relationships between causes and effects
- BNs are represented as a directed graph modeling conditional dependencies
- Nodes represent variables
- Arcs represent causal relationships between variables

Simple Bayesian Net Directed Causal Graph



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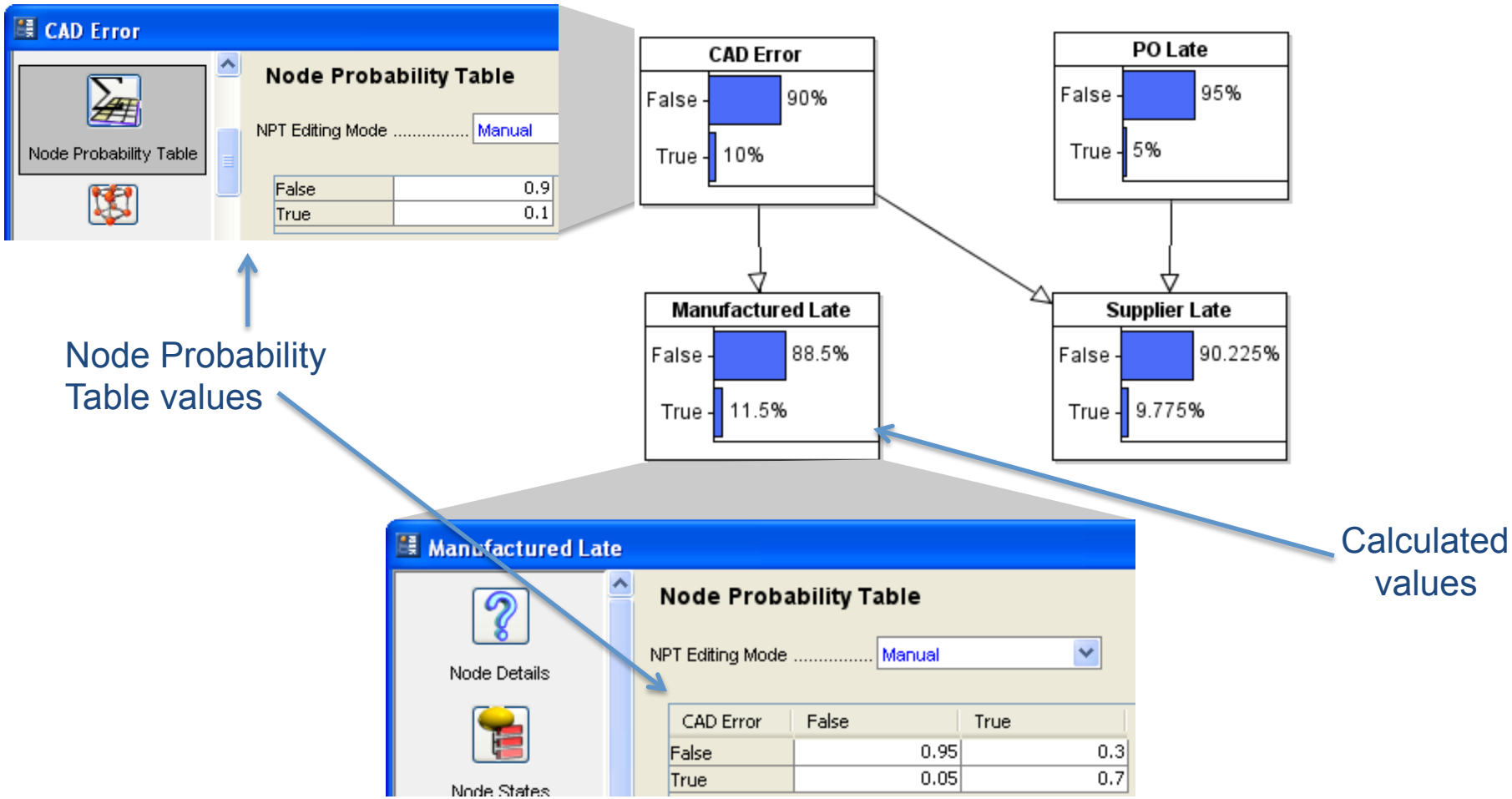
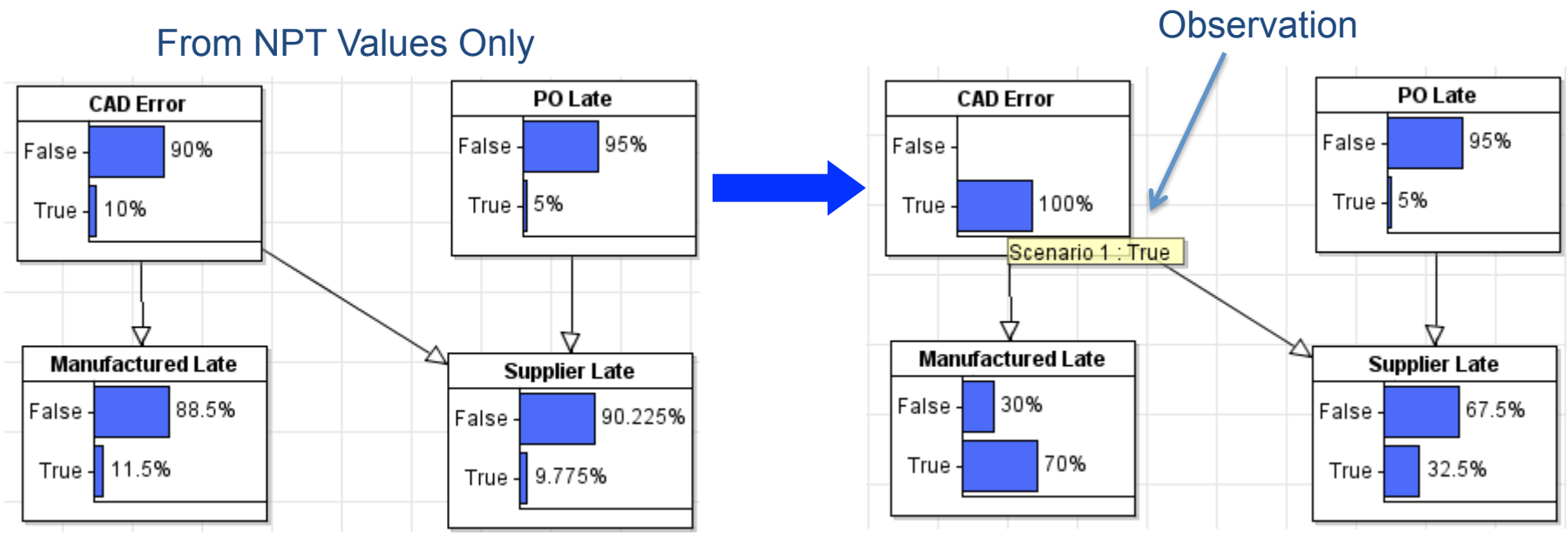
Calculated Values are Derived through Bayes' Theorem

- Node Probability Table (NPT) express conditional probability of node states



Adding Known or Observed Information Changes the Calculated Probabilities

- For example: entering observation, **a CAD Error**, about historical observations or future possibilities provides information about the risk probabilities such as:
  - This increases the calculated probability that it will be Manufactured Late and/or the Supplier Late
  - This provides additional information for decision making and risk management