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
By:
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Dr. Art Pyster
Dr. Robin Dillon-Merrill
Dr. Teresa Zigh
Dr. Richard Turner**

- ## 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)
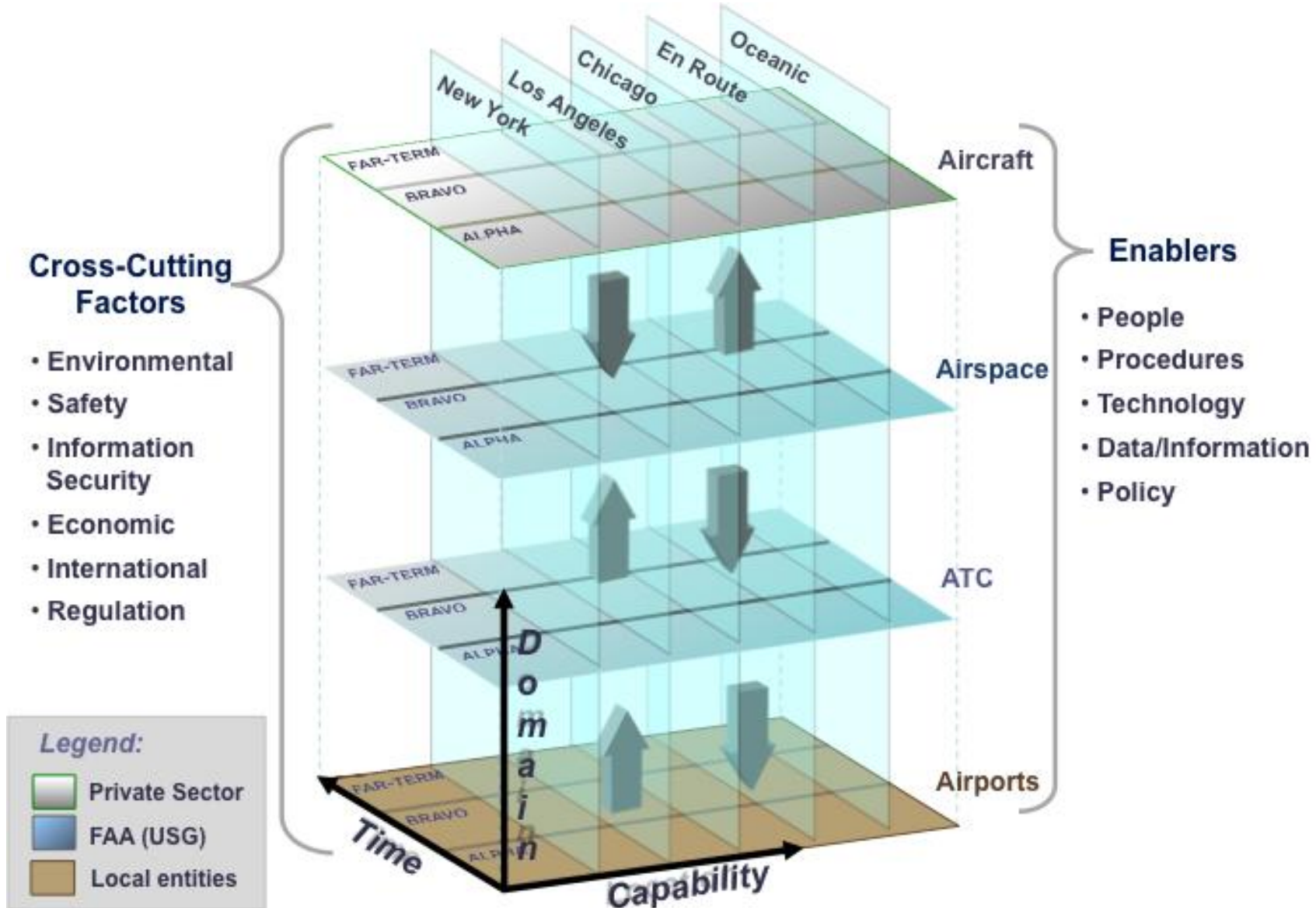
- ## Conclusions

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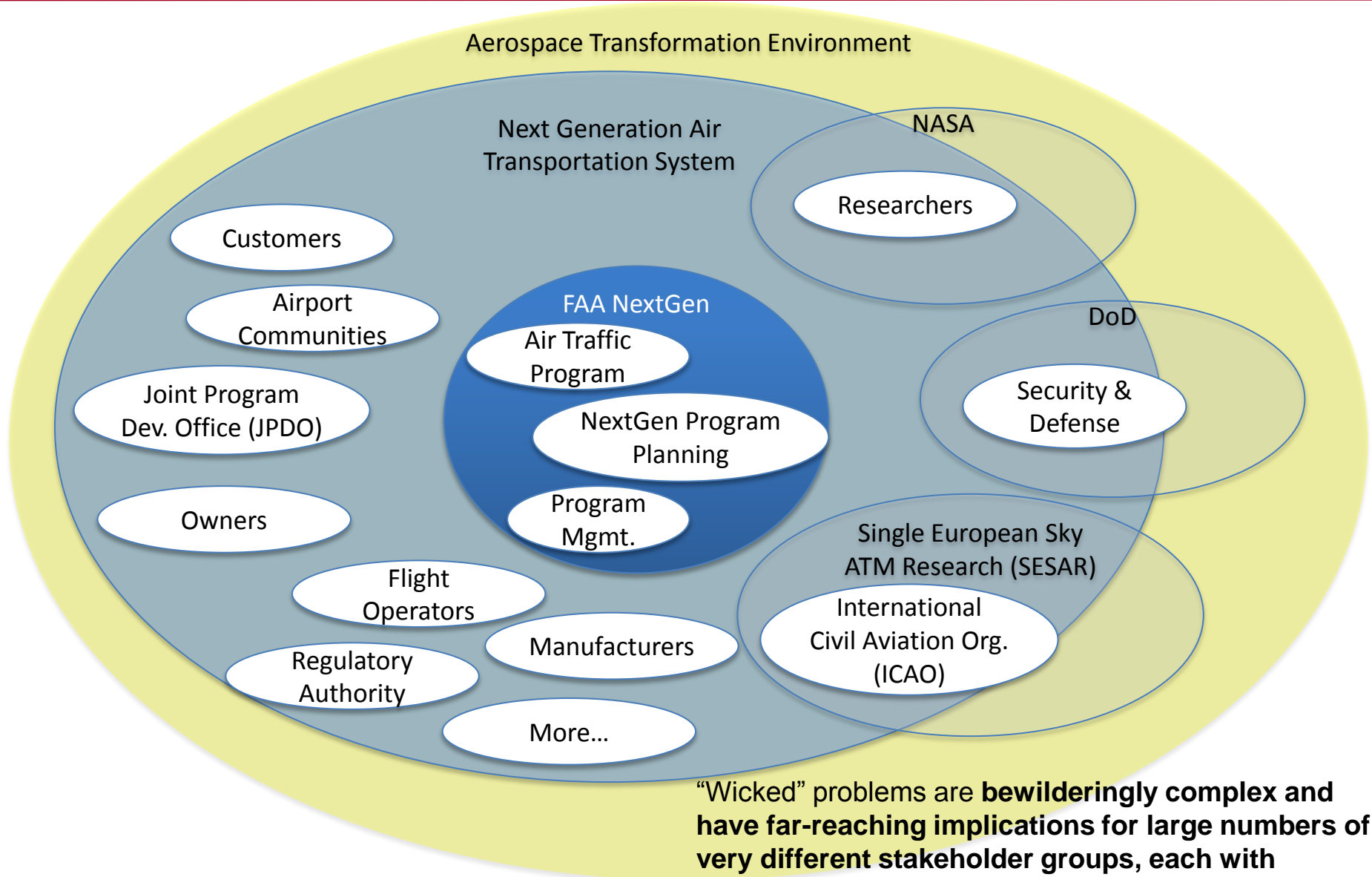
Part 1:
What is NextGen and
who are the Stakeholders?

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

Aerospace Transformation Environment

- Next Generation Air Transportation System
  - NASA
    - Researchers
  - DoD
    - Security & Defense
  - Single European Sky ATM Research (SESAR)
    - International Civil Aviation Org. (ICAO)
  - FAA NextGen
    - Air Traffic Program
    - NextGen Program Planning
    - Program Mgmt.
  - Customers
  - Airport Communities
  - Joint Program Dev. Office (JPDO)
  - Owners
  - Flight Operators
  - Manufacturers
  - Regulatory Authority
  - More…

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

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- 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
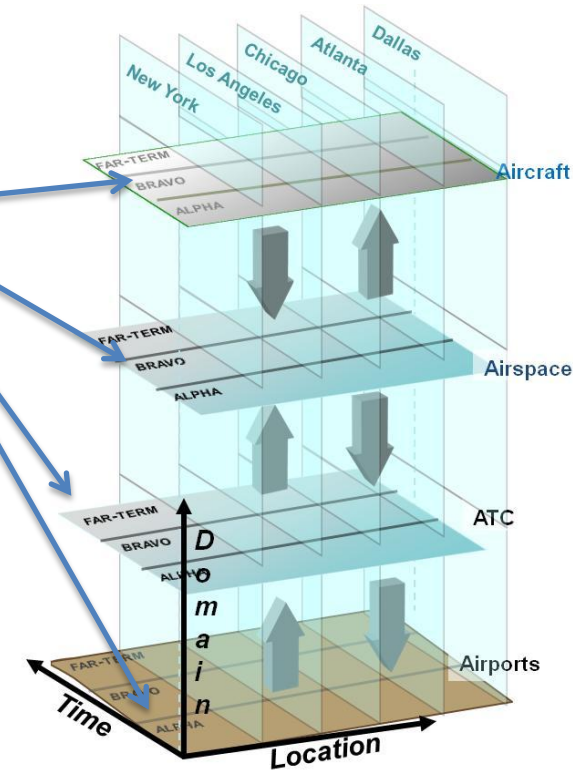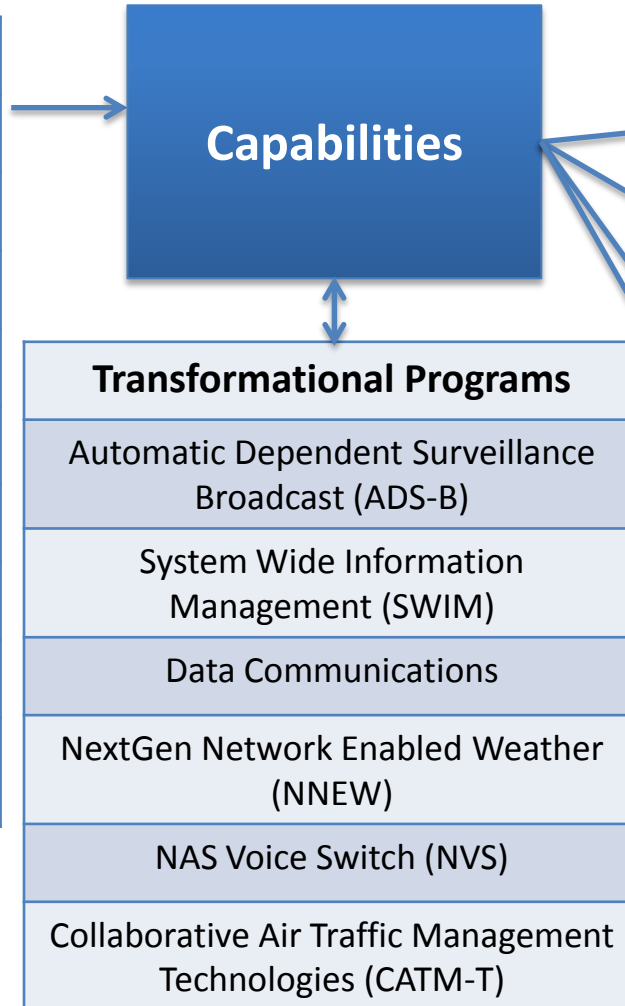

Mind Map of ~60 Stakeholders and Areas of Expertise

Part 2:
Problem
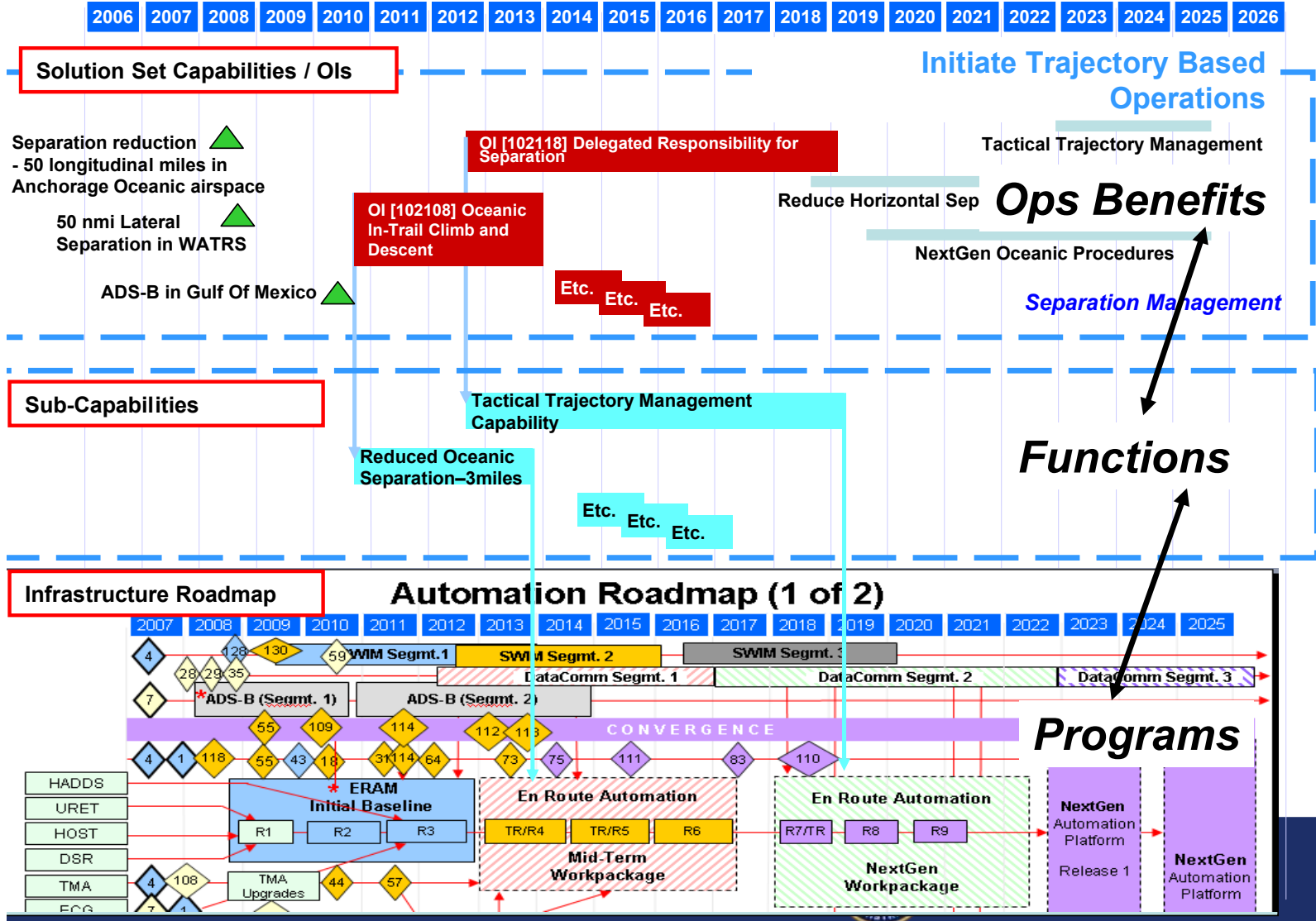# using
FAA NextGen SoS Terminology

- 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)
System Development (SysDev)
Technology Demonstrations and Infrastructure Development (Demos)

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

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What's so Challenging?

Success *only* occurs here.

Air Navigation Service Provider Infrastructure

Aircraft Capabilities

Airports Infrastructure

Data Communication

Automatic Dependent Surveillance Broadcast (ADS-B)

System Wide Information Management (SWIM)
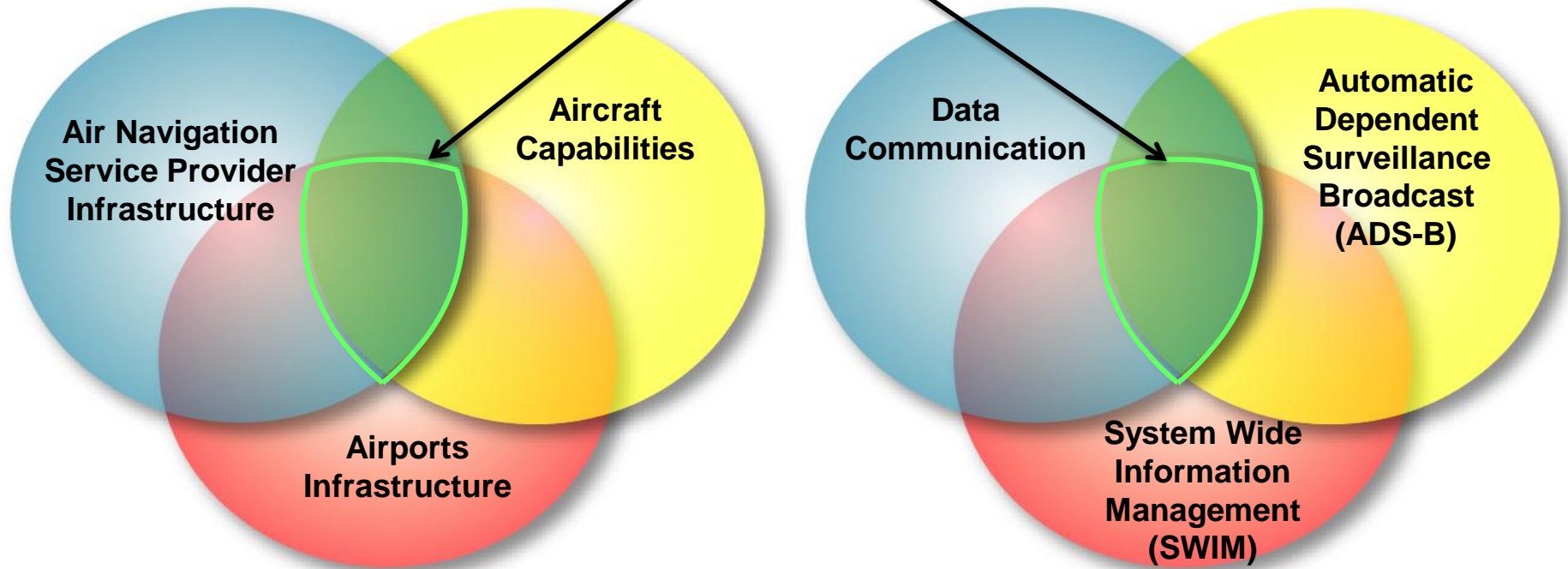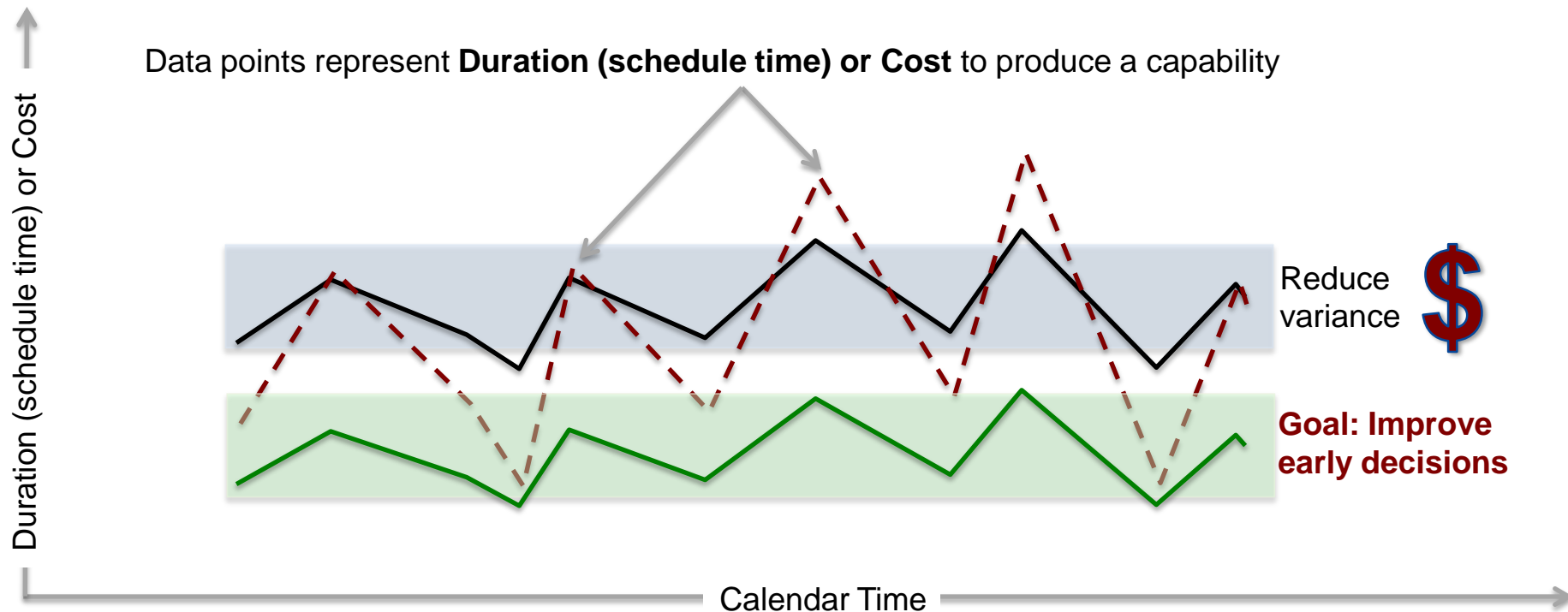
Example of Program Dependencies for Capability

- 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 are 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

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

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- 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

Data points represent **Duration (schedule time) or Cost** to produce a capability

Duration (schedule time) or Cost

Reduce variance
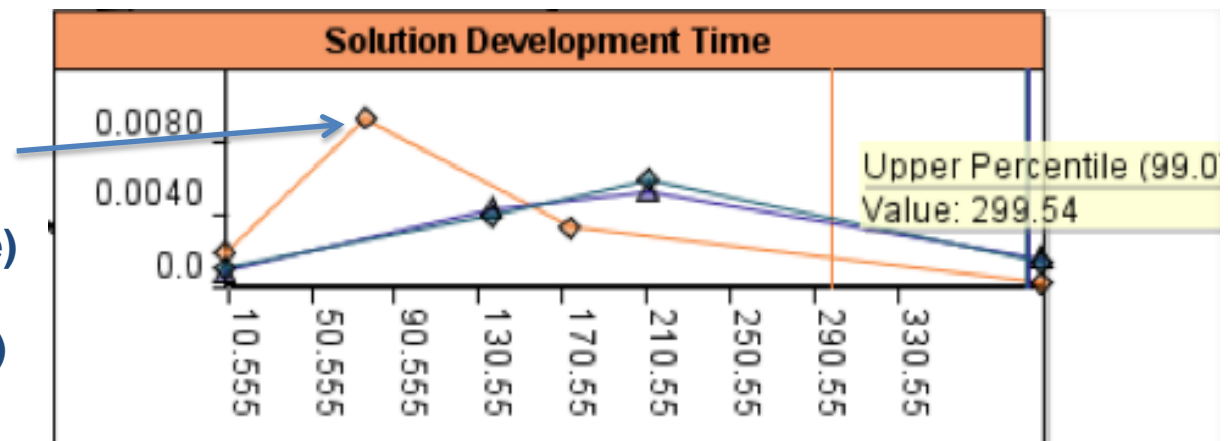
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Goal: Improve early decisions

Calendar Time

- A hybrid Bayesian network framework* combining causal and probabilistic representation of quantitative data and qualitative factors can provide probabilistic visualizations of cost, schedule and benefit risks that enable stakeholders to make better decisions of meeting cost, schedule and benefit targets than has been done with other methods and models to date

- Validation
  —Use historic cost, schedule and benefits data as quantitative inputs
  —Identify qualitative factors related to Acquisition Management System, Enterprise Architecture, Implementation Plan, and policies
    o As appropriate perform sensitivity analysis to identify most critical qualitative inputs
  —Compare historic estimates with model predictions
  —Compare historic actuals with model predictions

*This problem is too large to be a single Bayesian network; see other assumptions
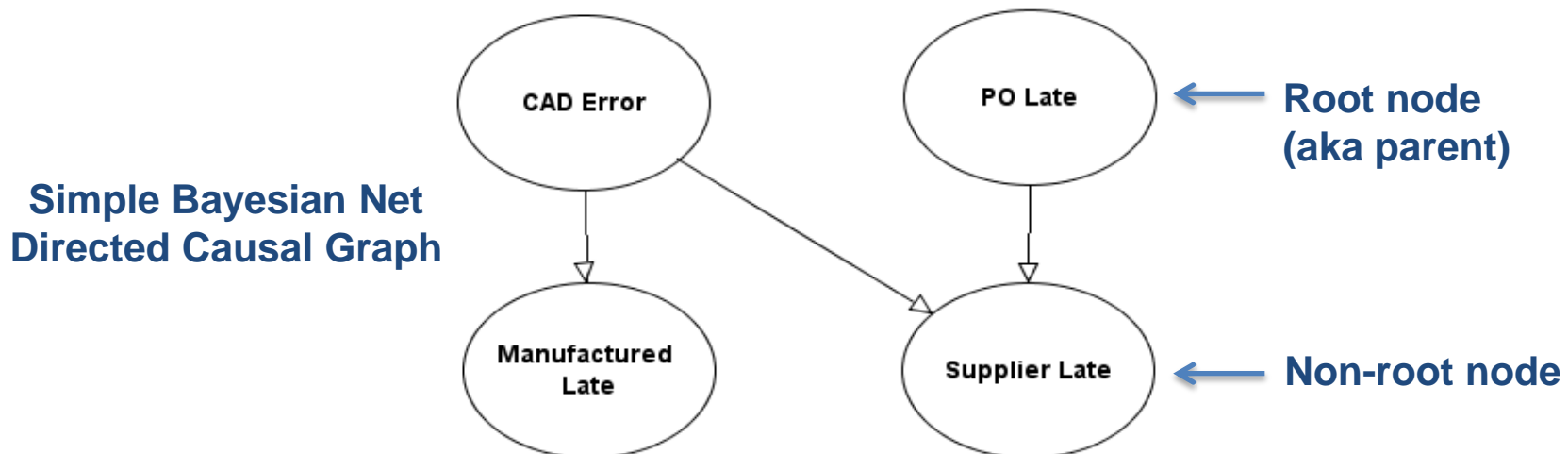
- Quantitative data may not represent all program factors in complex systems leading to inaccurate estimates

- Bayesian Network (BN) improve predictions by combining quantitative and qualitative (i.e. expert subjective judgment) data that capture and leverage causal relationships

- BNs provide results that can help people better think about the risks of the estimates

- Used similar BN pattern in the past

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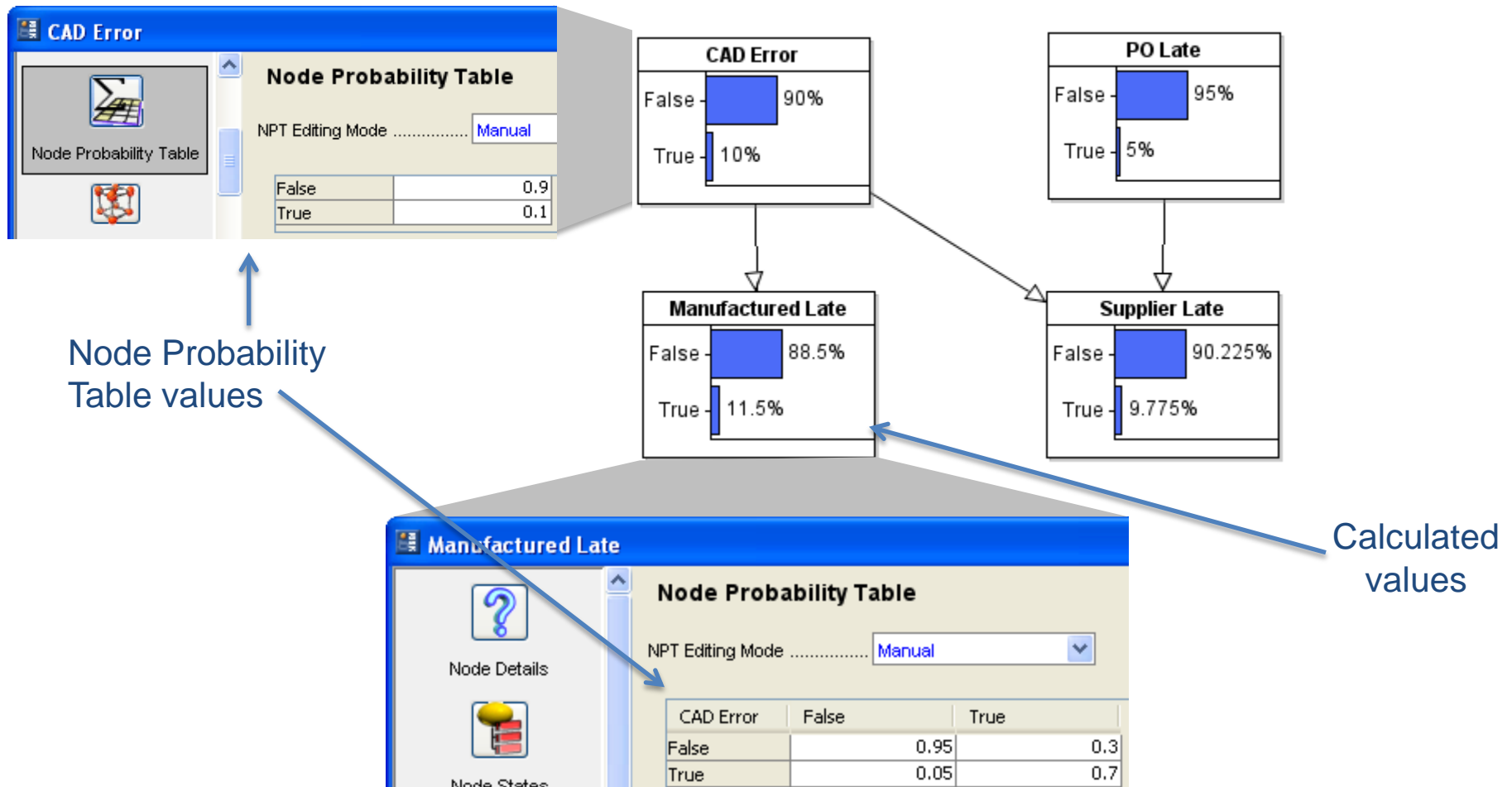

Solution Development Time

Upper Percentile (99.0
Value: 299.54

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- 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

CAD Error

PO Late ← **Root node (aka parent)**

Manufactured Late

Supplier Late ← **Non-root node**

Calculated Values are Derived through Bayes' Theorem

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

Node Probability Table values

Calculated values

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- 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
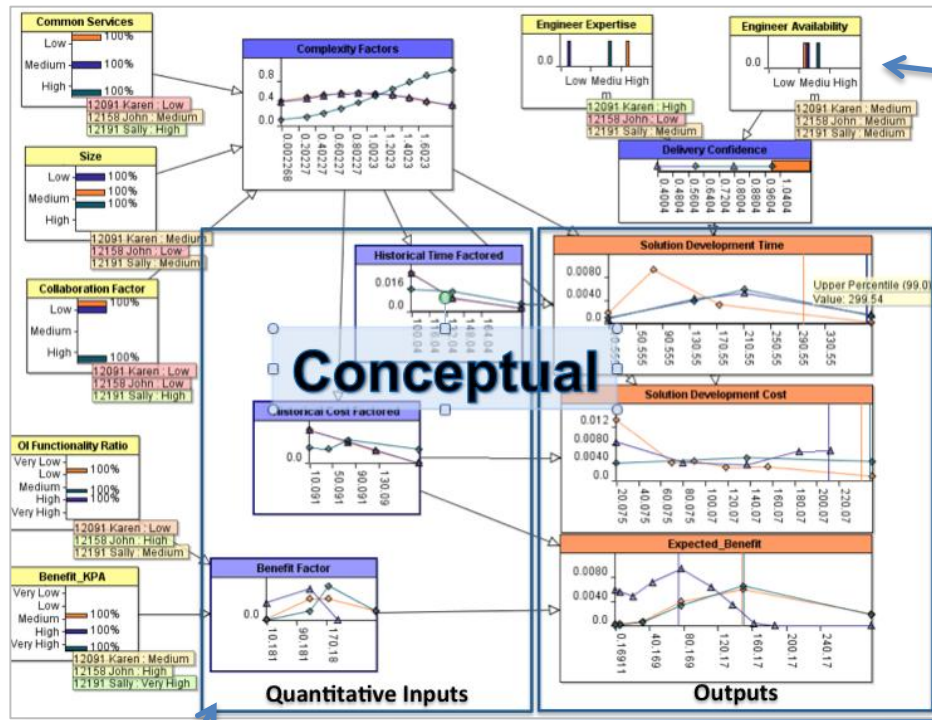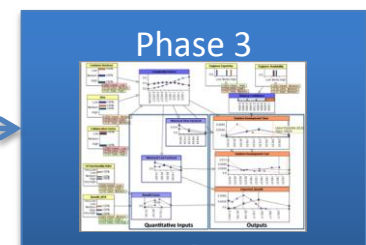

From NPT Values Only
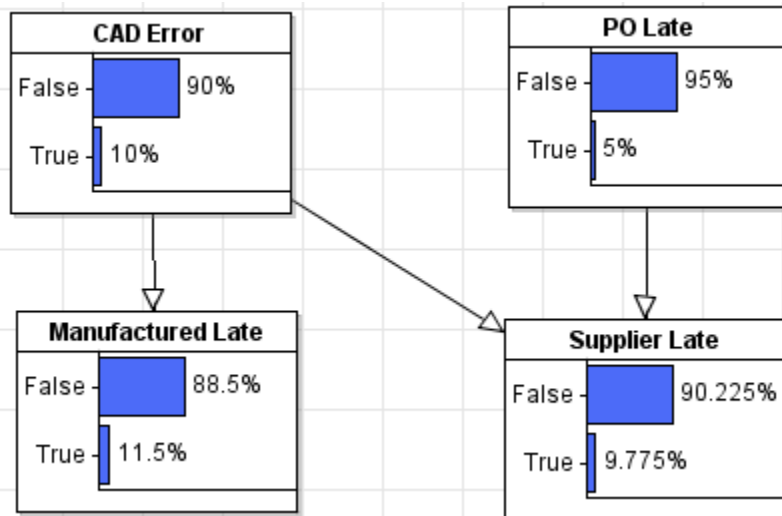
Observation
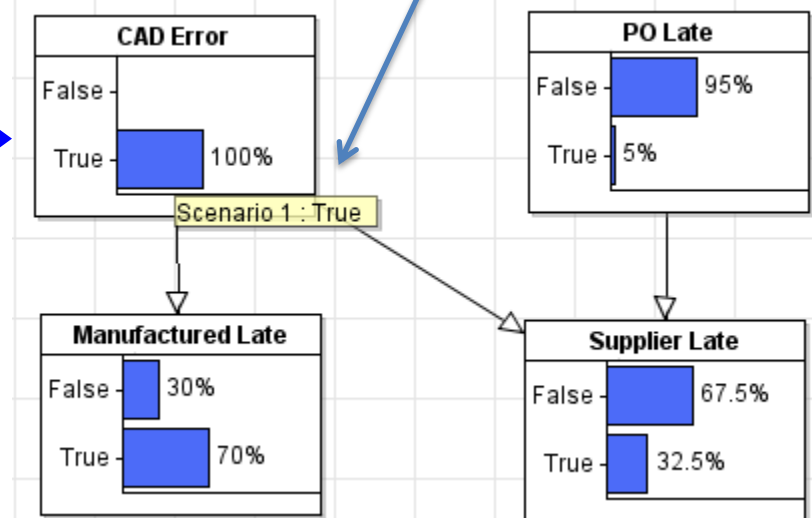
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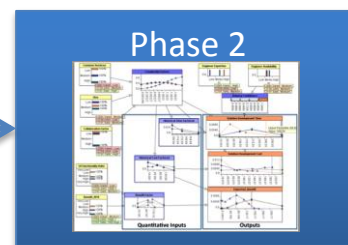Research Center

Input nodes (aka parent) relate to program factors

Conceptual BN illustrates a visualization of Cost, Schedule and Benefits Risk

Quantitative Inputs represent Historical information (Cost, Schedule Performance Benefits)
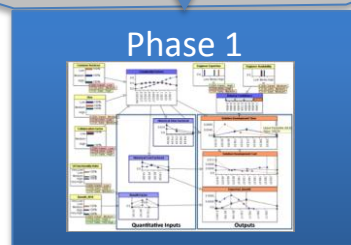
Conceptual Example Illustrating Cost, Schedule, Benefit, and Risk Tradeoffs

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Risk Matrix

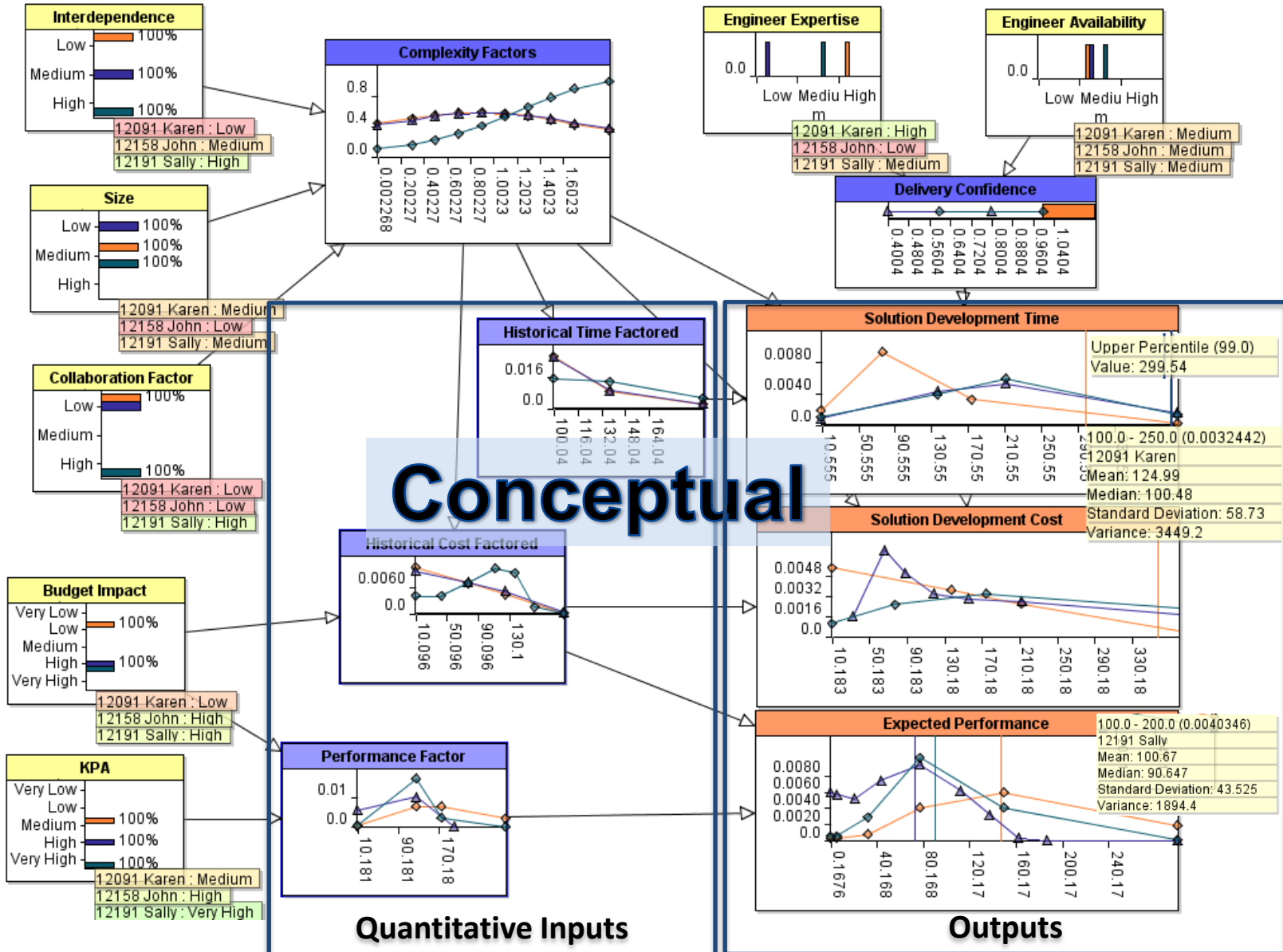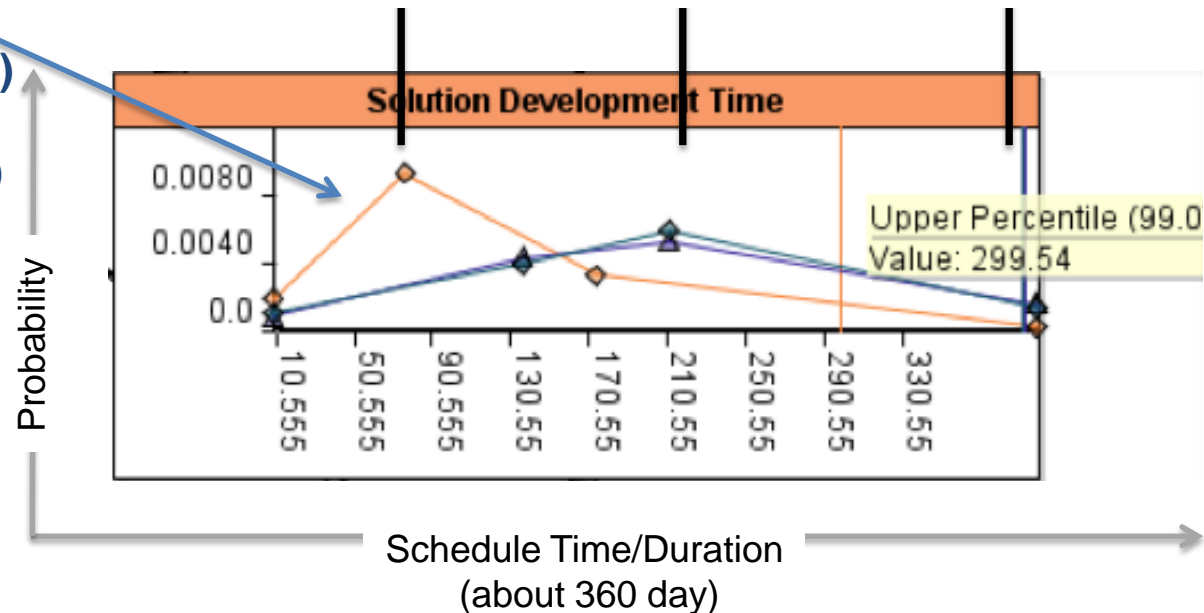| Likelihood			1	2	3	4	5
Near Certainty	E						
Highly Likely	D						
Likely	C						
Low Likelihood	B						
Not Likely	A						
			1	2	3	4	5
			Very Low	Low	Moderate	High	Very High
			Consequence				

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 that for blue or purple (less risk)

Solution Development Time

Probability

0.0080

0.0040

0.0

Upper Percentile (99.0
Value: 299.54

10.555
50.555
90.555
130.55
170.55
210.55
250.55
290.55
330.55

Schedule Time/Duration (about 360 day)

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- 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**"

- 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.

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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.