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STEVENS
INSTITUTE of TECHNOLOGY
THE INNOVATION UNIVERSITY

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

Results from Applying a Modeling and Analysis Framework to an FAA NextGen System of Systems Program

Presented to: NDIA 2013

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Outline

- Context
  - What is the Federal Aviation Administration's (FAA) NextGen
  - Using FAA NextGen System of Systems (SoS) Terminology
  - Who are the stakeholders?
- Results from models aligned to different phases of FAA Acquisition Management System (AMS)
  - Notional concept of AMS
  - Model for Concept & Requirements Definition (CRD) and Investment Analysis (IA) phase of AMS
  - Model for Solution Implementation phase of AMS
  - Model for Risk scenarios
- Conclusions
- Acknowledgment

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Risk-Informed Decision-Making: Leveraging What People Know in Changing Contexts

- Improving **collaboration** across SoS and disciplines
  - —NextGen is a complex SoS and rolling out capabilities is challenging due to:
    - Many factors
    - Complex interdependencies
    - Diverse set of stakeholders
- Developing a modeling and analysis framework to enable a **probabilistic process for risk-informed decision-making**
  - —Helps stakeholders understand cost, schedule, benefits, and risk tradeoffs
  - —Approach improves the accuracy of schedule and cost predictions
- 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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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

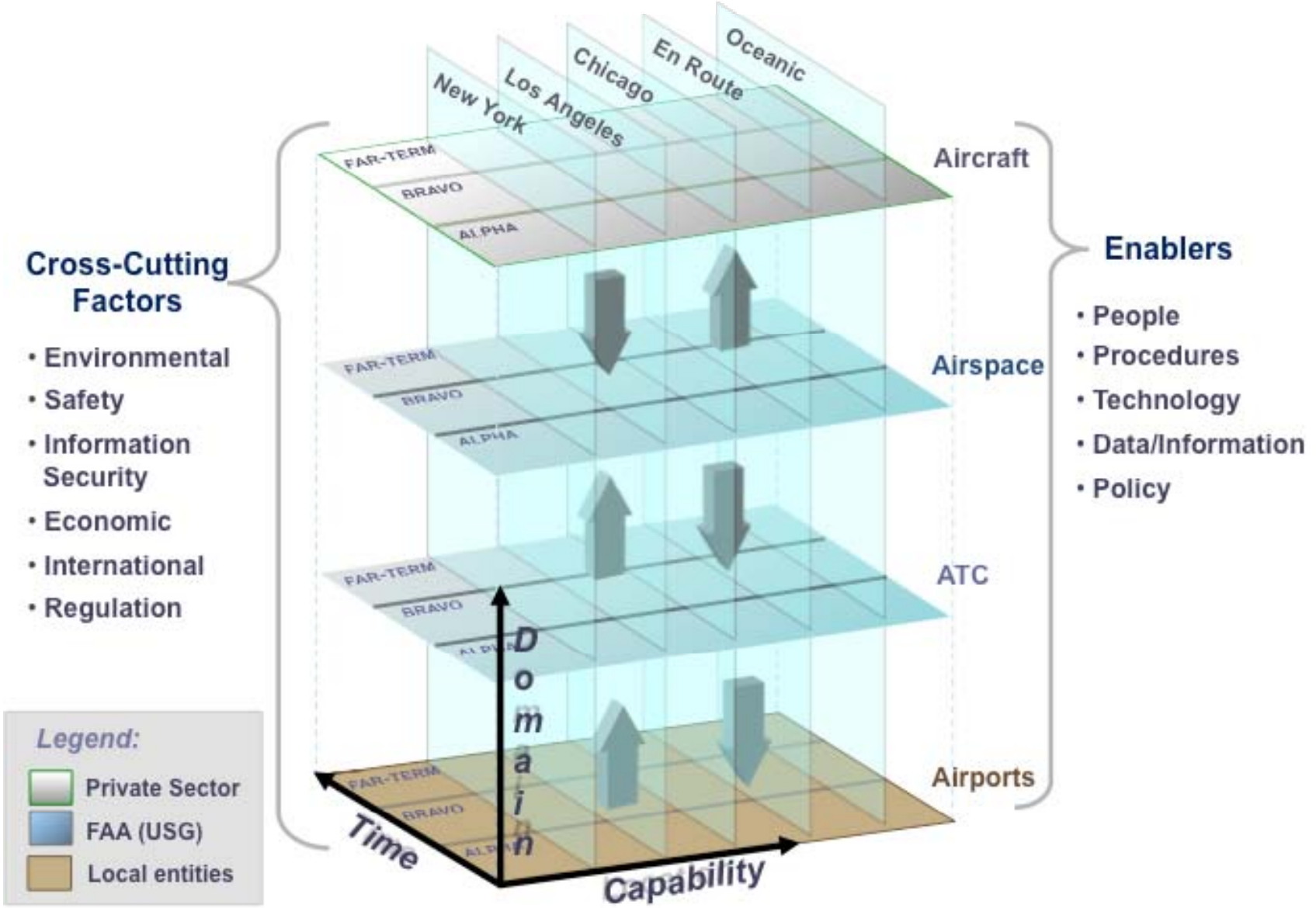

Image credit: Ron Stroup,
Chief Systems Engineer for Air-Ground Integration

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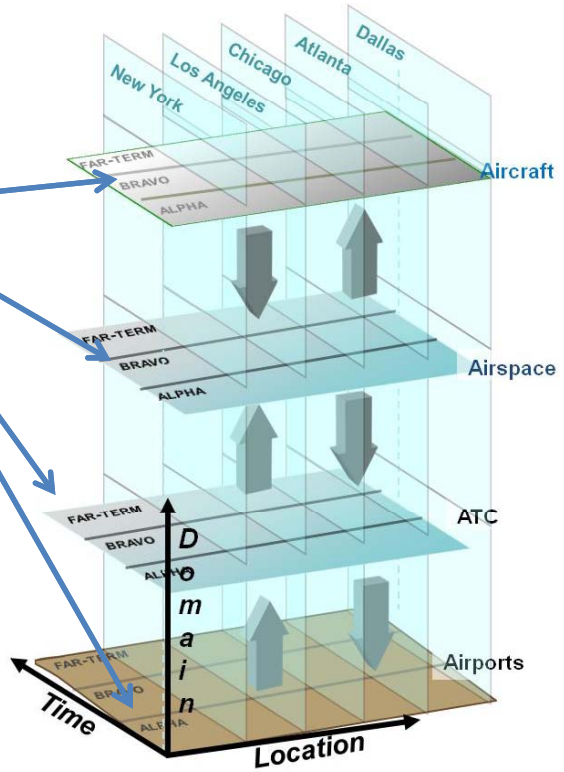
FAA NextGen Rolls Out Capabilities to SoS

- 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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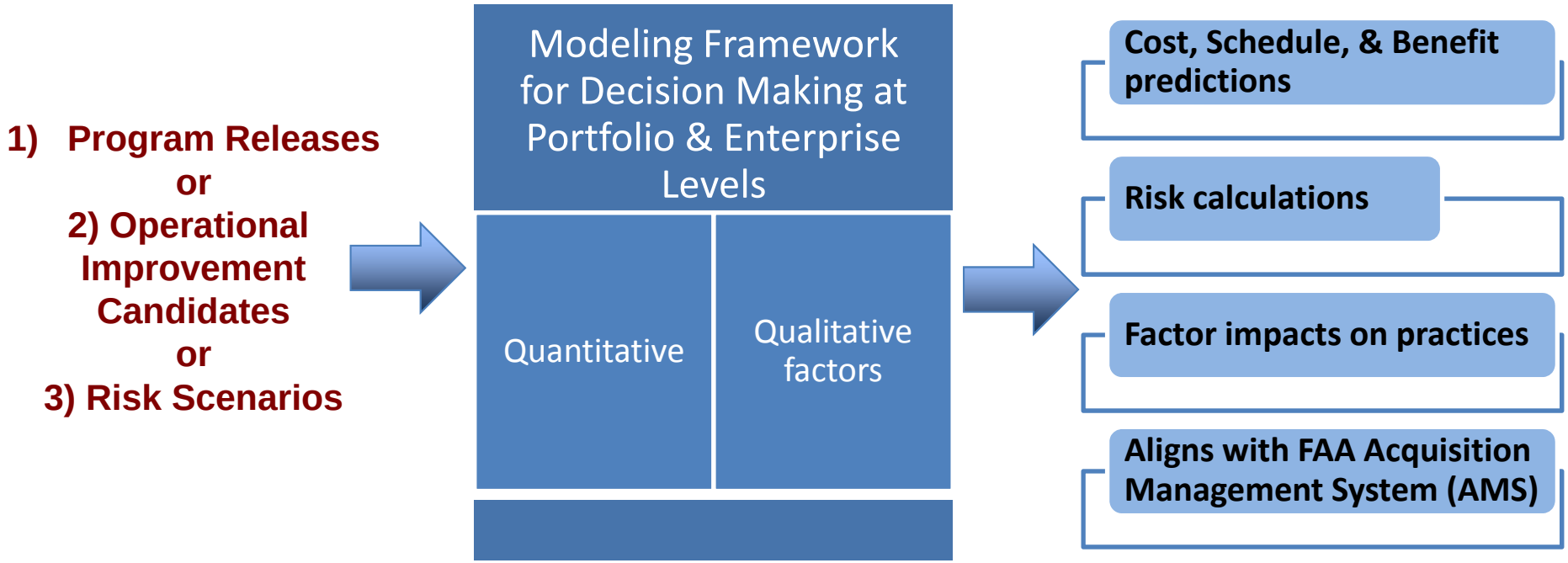
Objective Statement from Kickoff Meeting

- **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
  - —**Predictive Model for Estimating Cost, Schedule, Benefits, with Visualizations to aid in Risk-Informed Decision-making**



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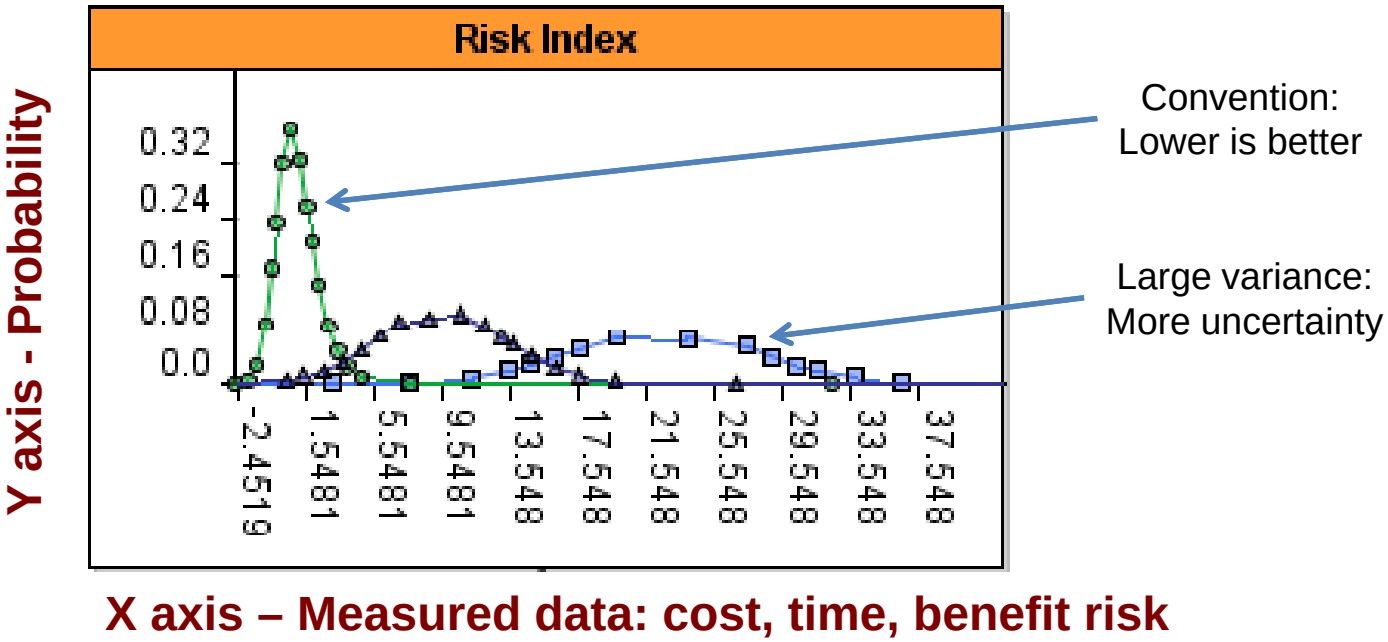
Definitions, Terminology and Notations

- Risk: the degree of probability of a loss*
- Probability: (1) the chance that something will happen; (2) a measure of how often a particular event will happen*
- Variance: an amount of difference*



*www.merriam-webster.com

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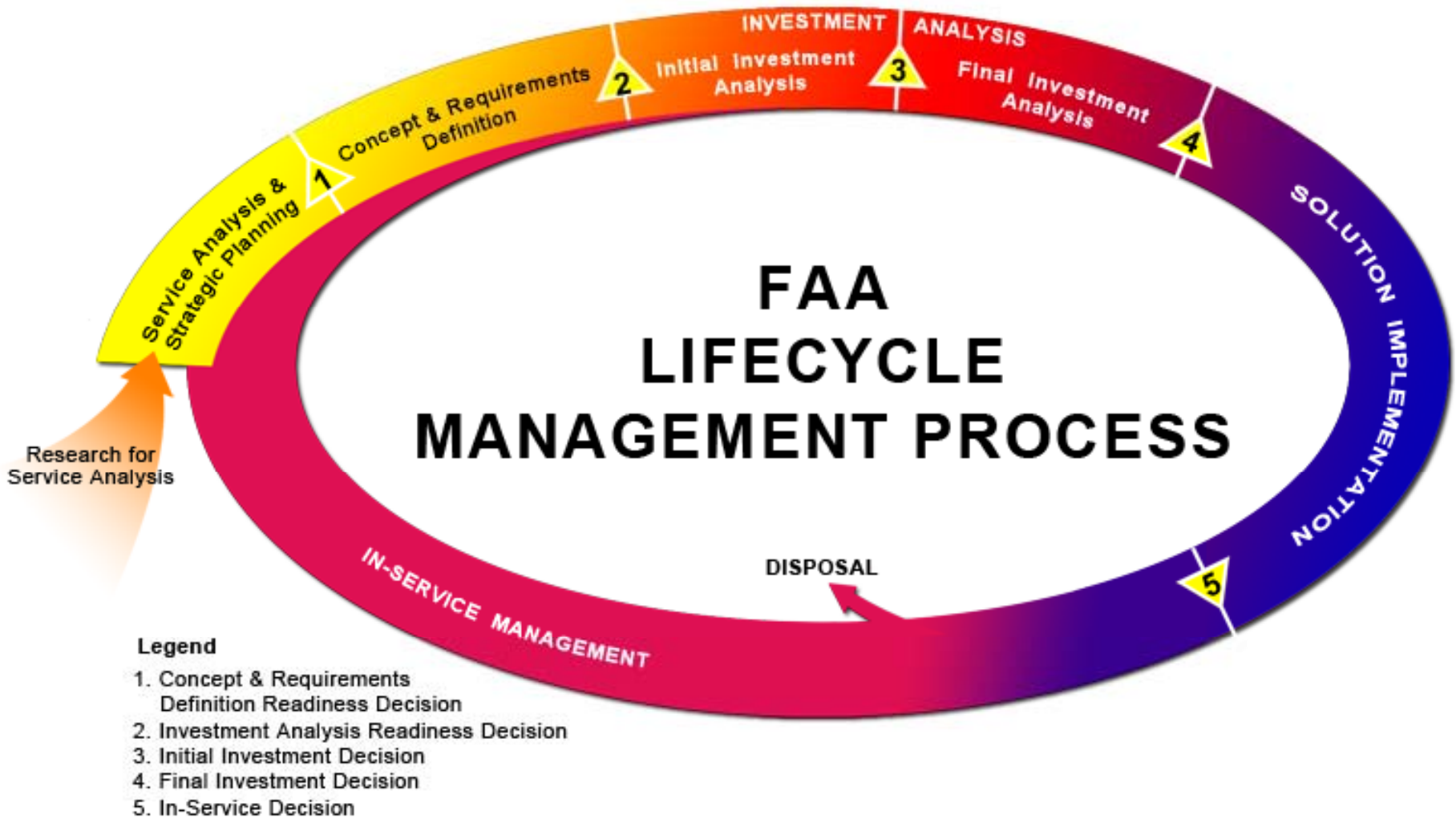
Developed Models to Support Decision Making for FAA AMS



FAA Acquisition Management System (AMS) (http://fast.faa.gov/)

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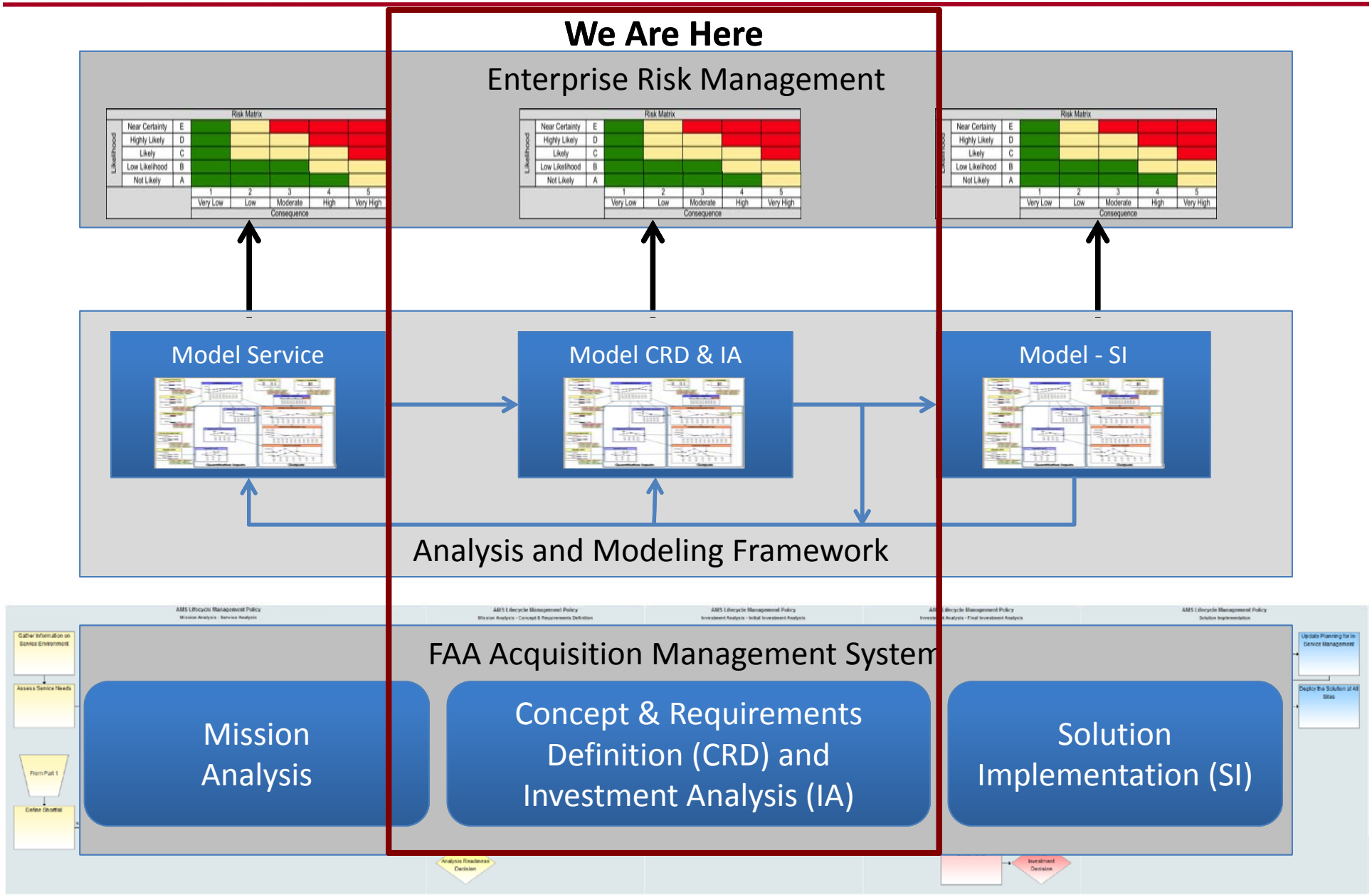
Model Aligns Primarily with CRD and Investment Analysis Aspects of FAA AMS



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Objective for CRD and IA Models – Moving OIIs through Process

- Improve prediction of schedule (and cost) for Operational Improvement Increments through the CRD and IA decision points?
- Improve the collaboration to understand the risks at the different decision points during this process?
- Understand the factors that impact the risk during this process?
- Quantify the risk?

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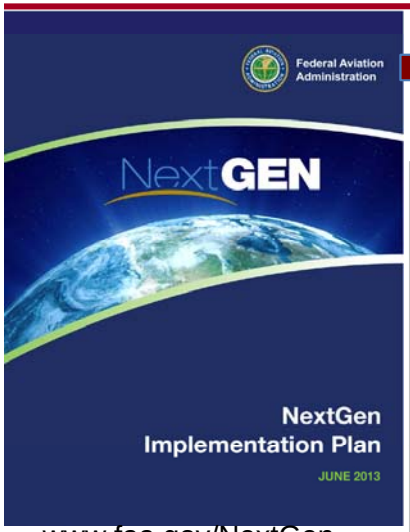
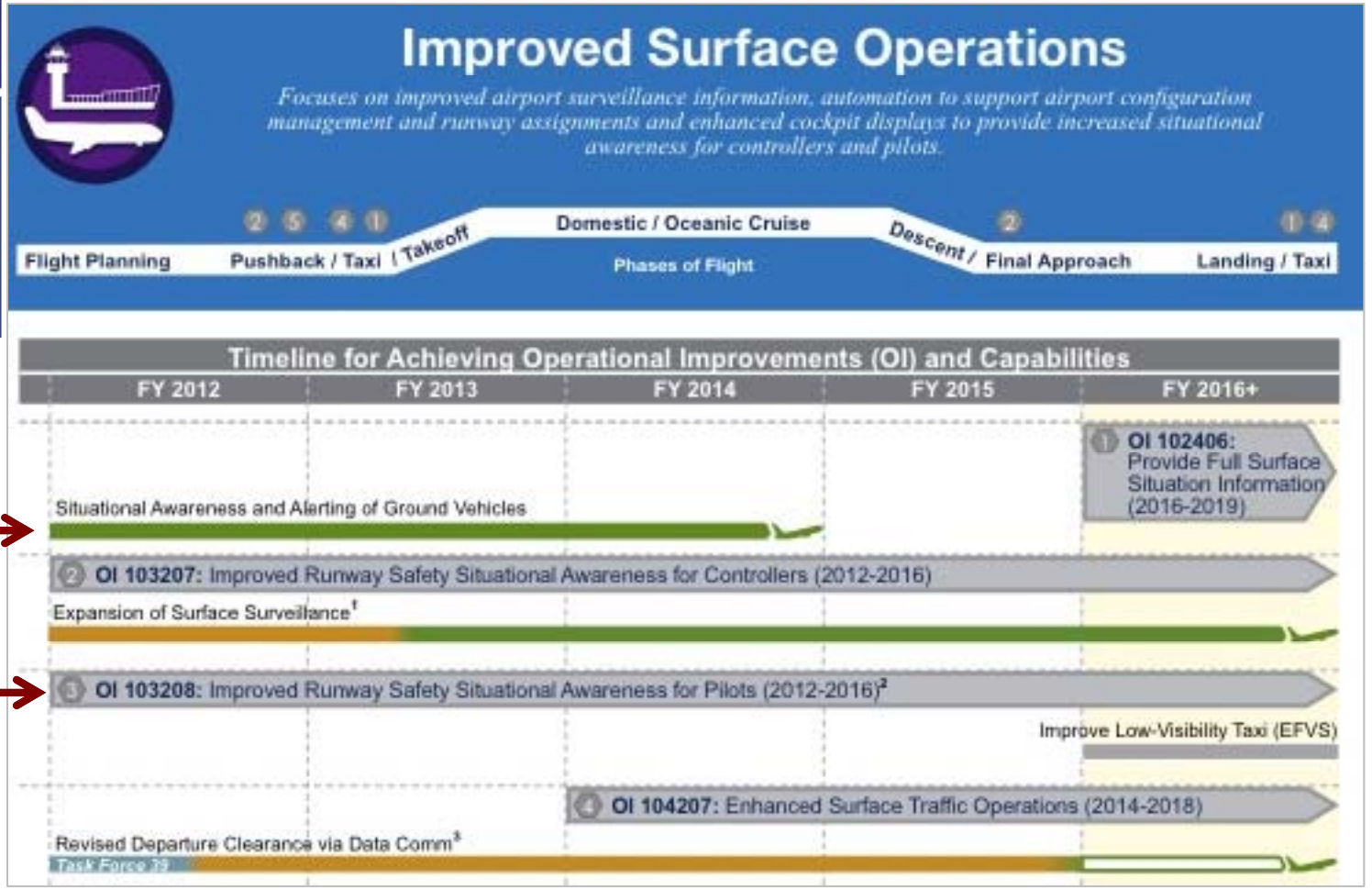
Example Implementation Portfolio From NextGen Implementation Plan



www.faa.gov/NextGen

Portfolio (1 of 10)



Timelines:

Operational Improvement Increment

Operational Improvement

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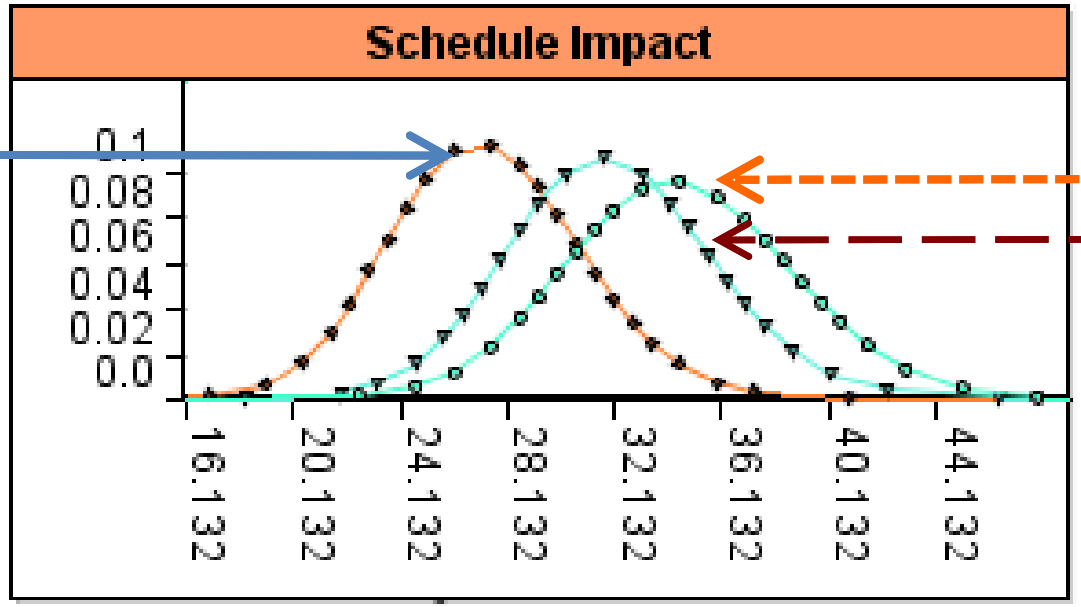
Improved Surface Portfolio Example

- Three SME inputs illustrate difference in schedule of ~7 months based on different beliefs in factors



Operational Improvement Increments	Mean
Situational Awareness and Alerting of Ground Vehicles	27.4
	32.0
	34.6

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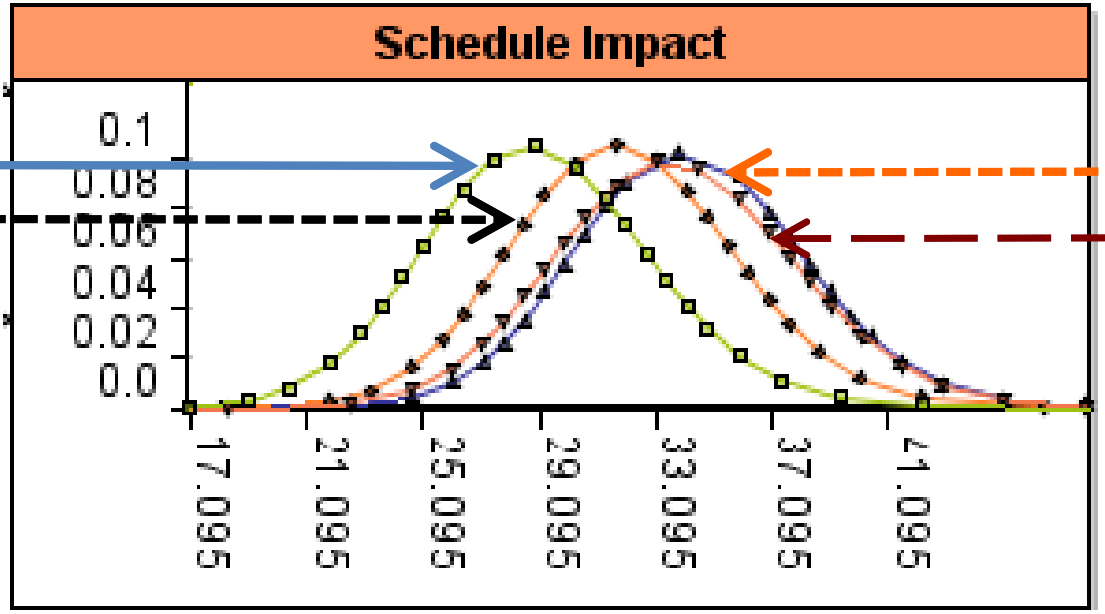
Time-Based Flow Management Portfolio Example

- Maximum difference more than 8 months for Operational Improvement



Operational Improvement Increments	Mean
Extended Metering	32.1
Arrival Interval Management Using Ground Automation	25.3
Use RNAV Route Data to Calculate Trajectories Used to Conduct TBM Operations	33.9
Integrated Departure/Arrival Capability	34.1

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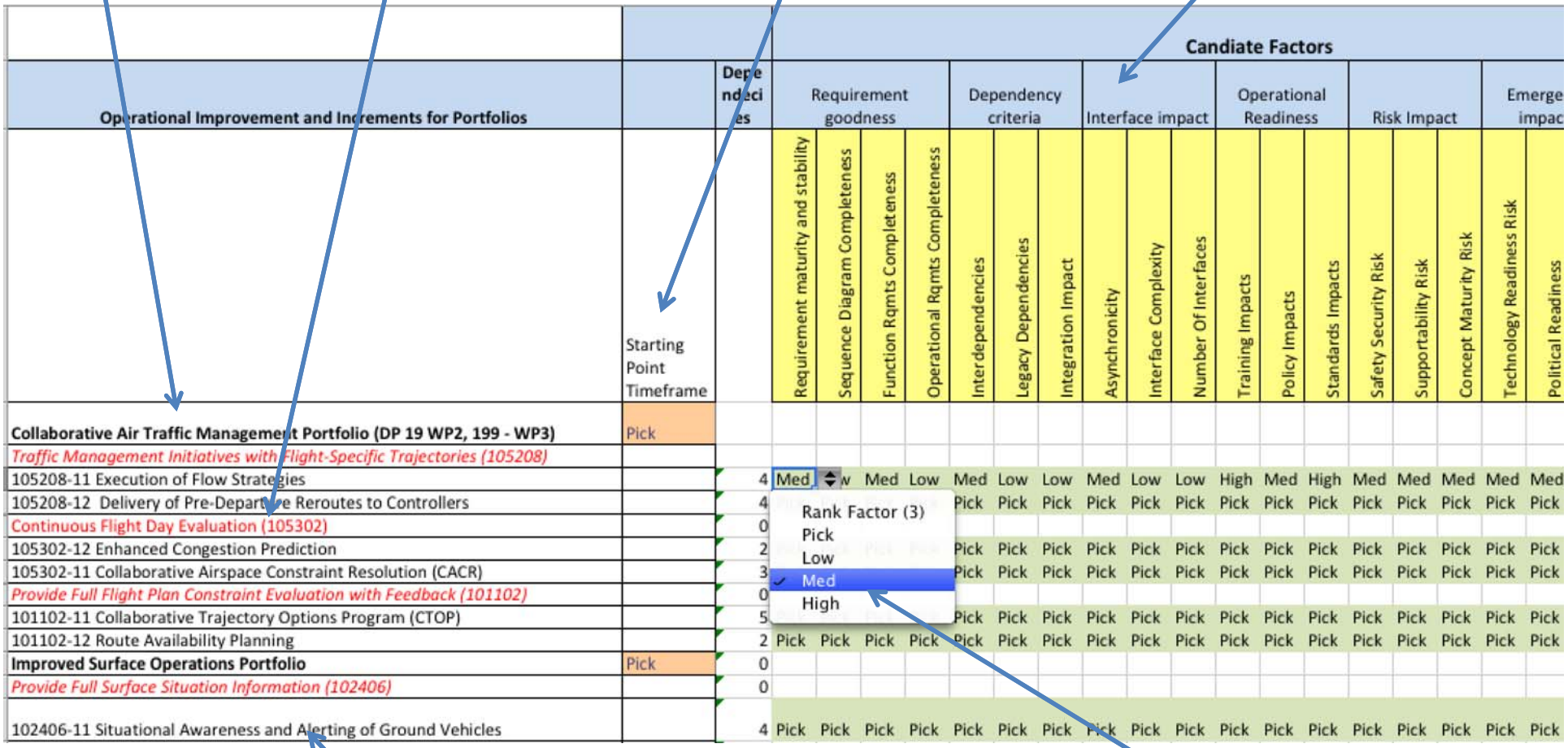
SMEs Use Spreadsheet Collection Instrument to Assign Factor Values to Each OII

Portfolio

Operational Improvement

Time Point in CRD & IA

Factors (by Category)



Operational Improvement and Increments for Portfolios	Starting Point Timeframe	Dependencies	Candiate Factors: Requirement goodness — Requirement maturity and stability	Requirement goodness — Sequence Diagram Completeness	Requirement goodness — Function Rqmts Completeness	Requirement goodness — Operational Rqmts Completeness	Dependency criteria — Interdependencies	Dependency criteria — Legacy Dependencies	Dependency criteria — Integration Impact	Interface impact — Asynchronicity	Interface impact — Interface Complexity	Interface impact — Number Of Interfaces	Operational Readiness — Training Impacts	Operational Readiness — Policy Impacts	Operational Readiness — Standards Impacts	Risk Impact — Safety Security Risk	Risk Impact — Supportability Risk	Risk Impact — Concept Maturity Risk	Emerge impac — Technology Readiness Risk	Emerge impac — Political Readiness
Collaborative Air Traffic Management Portfolio (DP 19 WP2, 199 - WP3)	Pick																			
Traffic Management Initiatives with Flight-Specific Trajectories (105208)																				
105208-11 Execution of Flow Strategies		4	Med	w	Med	Low	Med	Low	Low	Med	Low	Low	High	Med	High	Med	Med	Med	Med	Med
105208-12 Delivery of Pre-Departure Reroutes to Controllers		4					Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick
Continuous Flight Day Evaluation (105302)		0																		
105302-12 Enhanced Congestion Prediction		2					Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick
105302-11 Collaborative Airspace Constraint Resolution (CACR)		3					Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick
Provide Full Flight Plan Constraint Evaluation with Feedback (101102)		0																		
101102-11 Collaborative Trajectory Options Program (CTOP)		5					Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick
101102-12 Route Availability Planning		2	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick
Improved Surface Operations Portfolio	Pick	0																		
Provide Full Surface Situation Information (102406)		0																		
102406-11 Situational Awareness and Alerting of Ground Vehicles		4	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick	Pick

Rank Factor (3)
Pick
Low
✓ Med
High

Operational Improvement Increment (OII)

Menu for selecting factors value (L, M, H)

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Collection Spreadsheet has Factor Guidelines on Factors-Meaning Definition Worksheet

Factor Category	Factors	General: These factors should apply to most Operational Improvements that are Pre-implementation.	Ranking Levels
Requirement goodness	Requirement maturity and stability	- If there is near 90-95% confidence that the requirements are unlikely to change and that they are well defined and understood by the stakeholders (developer, PM, operators), then High (H), - if there is some possibility that they will change then Medium (M), - otherwise Low (L).	H - Best M - Medium L - Worst (negative impact)
	Sequence Diagram Completeness	The I2I process and EA require Sequence Diagrams to be used to characterize operational interactions and requirements. - If there is near 90-95% confidence that the Sequence Diagram are unlikely to change and that they are well defined and understood by the stakeholders (developer, PM, operators), then High (H), - if there is some possibility that they will change then Medium (M), - otherwise Low (L).	H - Best M - Medium L - Worst (negative impact)
	Function Rqmts Completeness	- If there is near 90-95% confidence that the Functional Requirements are unlikely to change and that they are well defined and understood by the stakeholders (developer, PM, operators), then High (H), - if there is some possibility that they will change then Medium (M), - otherwise Low (L).	H - Best M - Medium L - Worst (negative impact)
	Operational Rqmts Completeness	- If there is near 90-95% confidence that the Functional Requirements are unlikely to change and that they are well defined and understood by the stakeholders (developer, PM, operators), then High (H), - if there is some possibility that they will change then Medium (M), - otherwise Low (L). If Sequence Diagrams are used and they are complete, it is likely that the Operational Requirements will align with the same factor rating.	H - Best M - Medium L - Worst (negative impact)
Dependency criteria	Interdependencies	- If there are a large number of interdependencies (for example as reflected in the Increment-to-System Mapping sections of NSIP 5.0), - if there are a lot of internal system interdependencies, then High (H), - if the capability has only a few interdependencies the Low (L), - otherwise Medium (M).	L - Best M - Medium H - Worst (negative impact)
	Legacy Dependencies	- If there are a large number (relative, but could be > 3) of Legacy Dependencies (and/legacy components) then High (H), - if the capability has no interdependencies the Low (L), - otherwise Medium (M) If there are Legacy systems for which the new OII is to replace, and the current capabilities of the Legacy system are not well documented (e.g., only know in the code, or if there are a lot of variants that related to different airports), then consider making the rating High (H) or Medium (M), otherwise Low (L).	L - Best M - Medium H - Worst (negative impact)
	Integration Impact	- If the number of dependencies associated with the previous two factors is Low, then most likely Low (L), - if integration across other systems involves other organization, collaboration operators, changes in policies, safety, tools and technology, then High (H), - otherwise Medium (M).	L - Best M - Medium H - Worst (negative impact)

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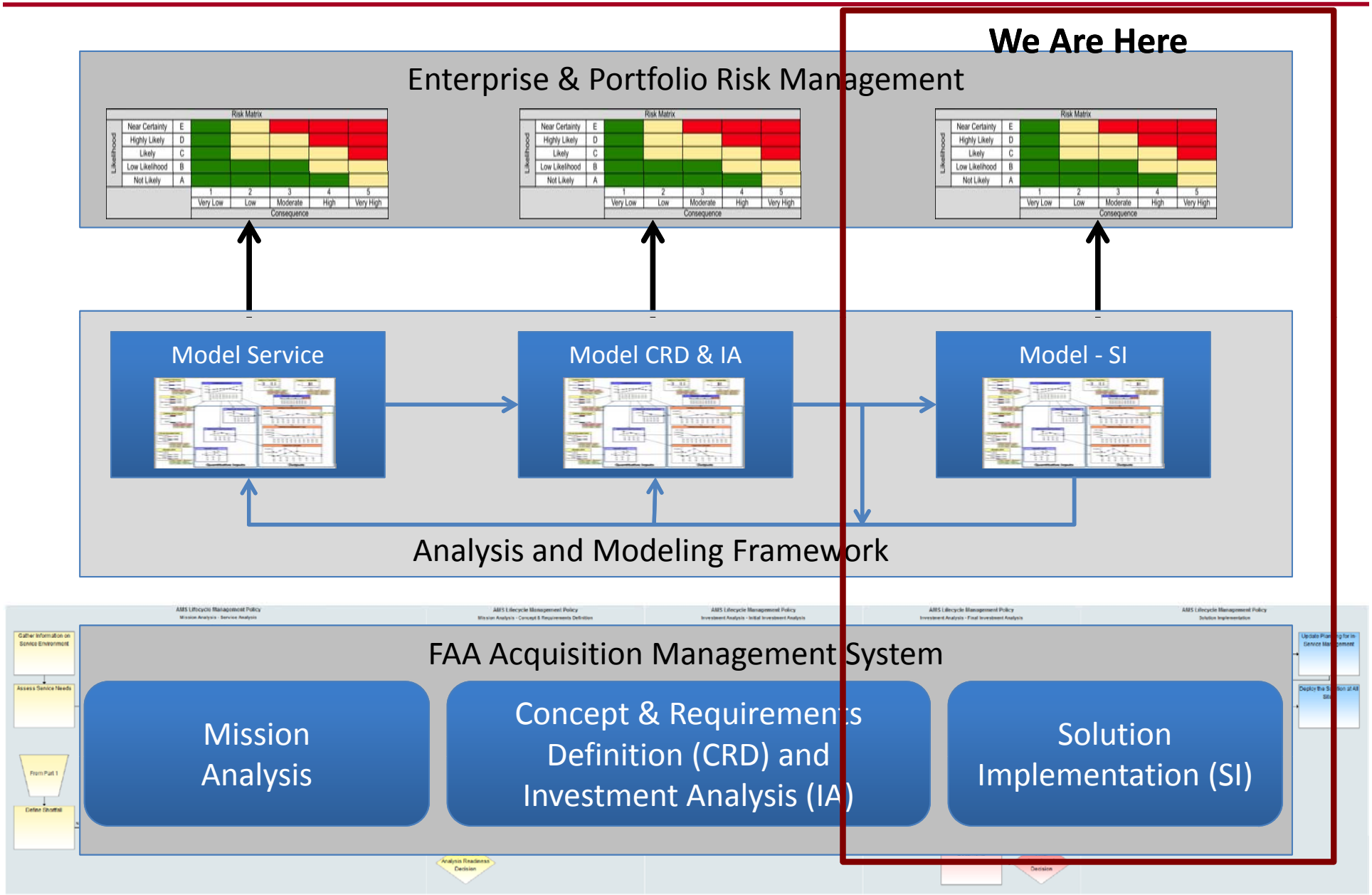
Approach: Developed Models Align with FAA AMS to Address Varying Lifecycle Factors



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Objective for Solution Implementation Model

- Given historical information (cost/schedule)
  - —Calibrate model based on factors
  - —Use model for future predictions
- Can one model apply to all programs executing in Solution Implementation?
  - —Do the same factors apply to both systems in the solution implementation phase?
  - —Are the causal relationships between factors the same?
    - o As reflected in the Bayesian network (BN) model
  - —Are the factor weightings the same?
    - o As reflected by the node probabilities in the BN model

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Use Pull Down Menu to Select Value (Low, Med, High) that is most applicable

1) Add Quantitative Data (Start Date and Actual Release Date)

Factors Categories
(Next Slide for Details)

				Estimate of Effort			Architecture Stability			Deployment Variability			Goodness of Sta	
ID	Plan Start Date (1)	Actual Start Date (2)	Planned End Date	SLOC Size (7)	# of Interface Elements	# Req/ NCPs	Complexity	PTR Density	PTR Closing Rate	Deployment Scope	Common Code base (Reuse)	Adaptation Magnitude	Operational Requirements Completeness	Functional Requirements Completeness
RB1	9/4/12	10/17/12	2/20/13	Very Low	Low	Low	Low	Low	High	Low	High	Low	High	High
RB2	3/30/12	3/30/12	10/9/12	Med	Low	Low	Med	Low	Med	Low	Low	w	High	Med
RB4	7/9/12	7/9/12	11/6/12	Med	Low	Low	High	Low	Low	Low		w	High	High
RB6	7/9/12	7/9/12	12/13/12	Med	High	Low	Med	Med	Med	Low		w	High	High
RB8	12/6/12	2/11/13	4/30/13	Med	Low	Low	Med	Low	Med	Low		w	High	High
RB10	8/16/12	8/16/12	3/15/13	Very Low	Low	Low	Low	Low	High	Low		w	High	High
RB11	11/26/12	12/6/12	3/27/13	Very Low	Low	Low	Low	Low	High	Low		ow	High	High

Pick
✓ Low
Med
High

2) Select Factor Values (Low, Med, High)

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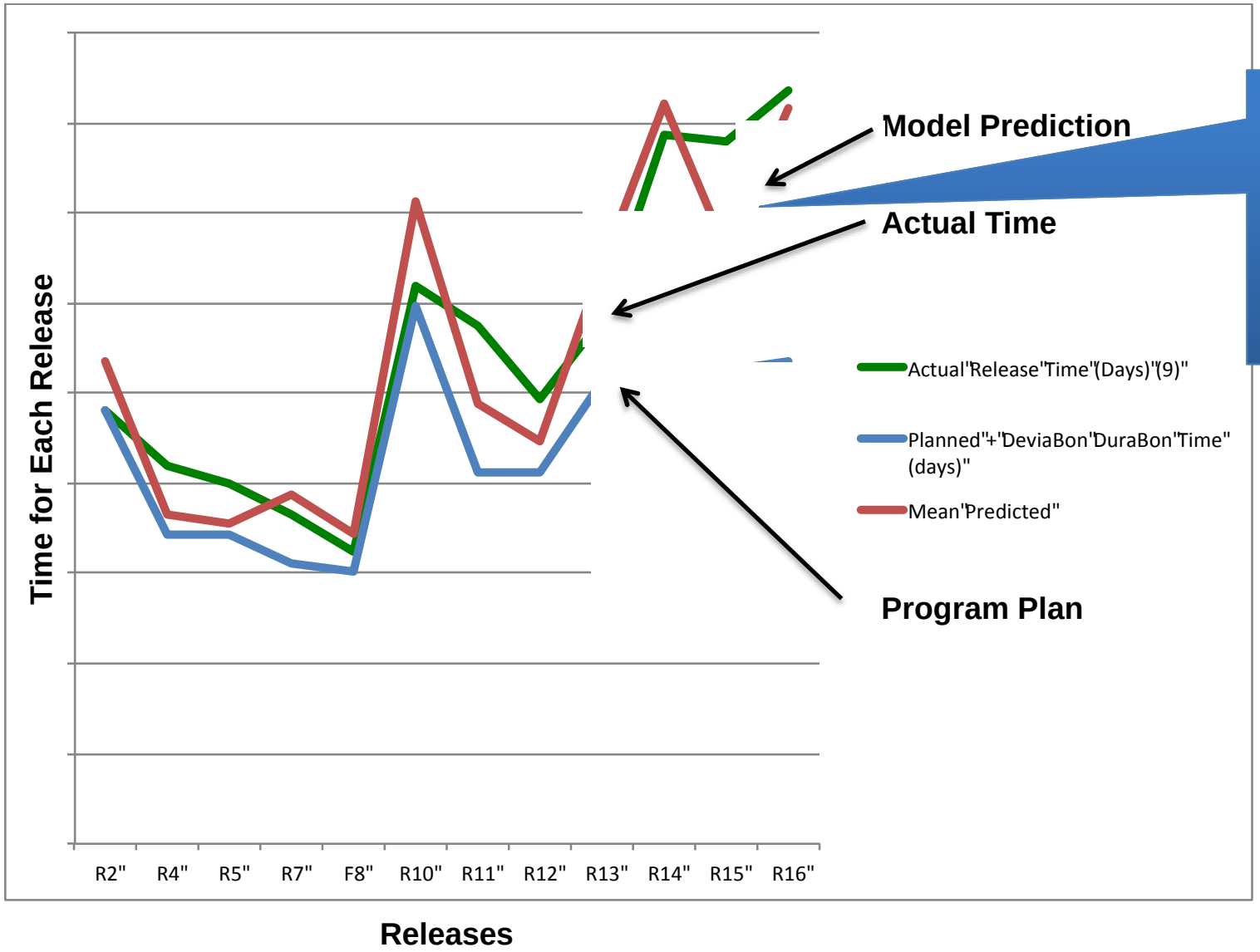
Comparison of Predicted, Actual, and Planned Schedule over Many Releases



We found out by talking with the program team that this release was split into two, and that might explain the inaccuracy of this point

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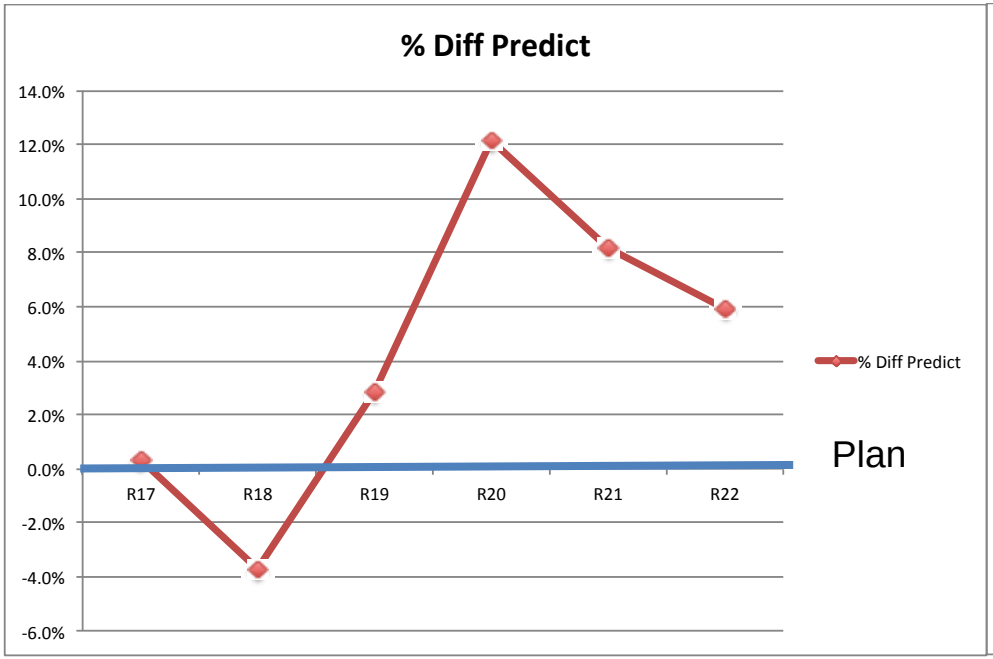
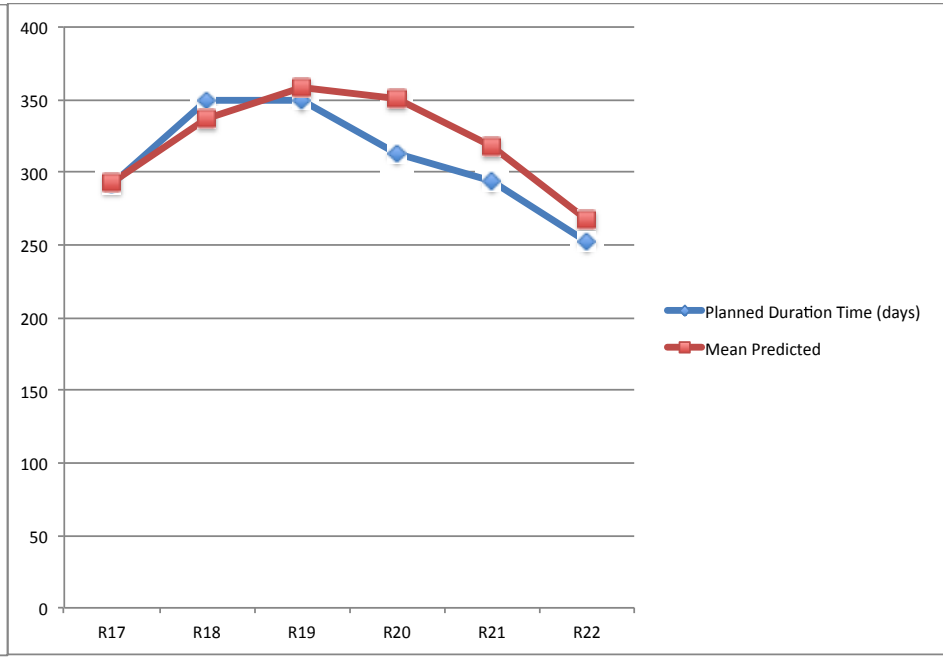
Summary Data for Cost Prediction/Estimation Releases R17 – R22 – Planned vs. Predicted

Release ID	Plan Date Released to Site	Planned Start Date	Planned Duration Time (days)	Planned in Months	Mean Predicted	% Diff Predict
R17	8/31/13	11/12/12	292	9.7	293	0.3%
R18	3/31/14	4/15/13	350	11.7	337	-3.7%
R19	8/31/14	9/16/13	349	11.6	359	2.9%
R20	1/31/15	3/24/14	313	10.4	351	12.1%
R21	6/15/15	8/25/14	294	9.8	318	8.2%
R22	10/5/15	1/26/15	252	8.4	267	6.0%





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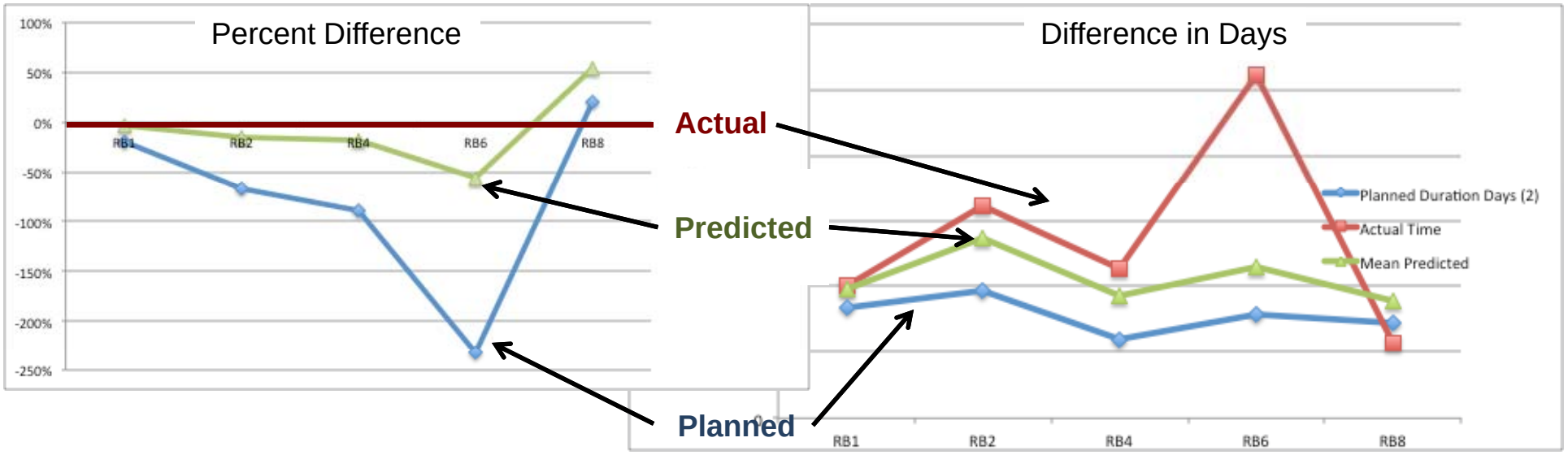
Project B – Revised Results

ID	Plan Start Date (1)	Actual Start Date (2)	Planned End Date	Start Delay	Planned Duration Days (2)	Actual Time	% Diff Cmp	Planned in Months	Mean Predicted	% Diff Predict
RB1	9/4/12	10/17/12	2/20/13	43	169	201	-19%	5.6	195	-3%
RB2	3/30/12	3/30/12	10/9/12	0	193	322	-67%	6.4	274	-15%
RB4	7/9/12	7/9/12	11/6/12	0	120	227	-89%	4.0	187	-18%
RB6	7/9/12	7/9/12	12/13/12	0	157	521	-232%	5.2	230	-56%
RB8	12/6/12	2/11/13	4/30/13	67	145	115	21%	4.8	177	54%
RB10	8/16/12	8/16/12	3/15/13	0	211			7.0	292	38%
RB11	11/26/12	12/6/12	3/27/13	10	121			4.0	167	38%



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Analysis of Solution Implementation Model

Questions	Answer	Comment
Do the same factors apply to both systems in the solution implementation phase?	Yes	Added new factor related to Service Orientation of Program and adjusted some causal relationships
Are the causal relationships between factors the same? • As reflected in the Bayesian network model	No	Changed some causal relationships related to Service Orientation Factor which reduce impact of Deployment Factor, Operational Requirements, increase impact of #Interfaces and a few others – model relevant to both Project A & B
Are the factor weightings the same? • As reflected by the node probabilities in model	Yes	We did make some adjustments to some of the weighting, but then examined results from updated model for both Project A and Project B
Are there missing factors?	Yes	Service Oriented Computing was the only new factor, and might apply to other Solution Implementation programs

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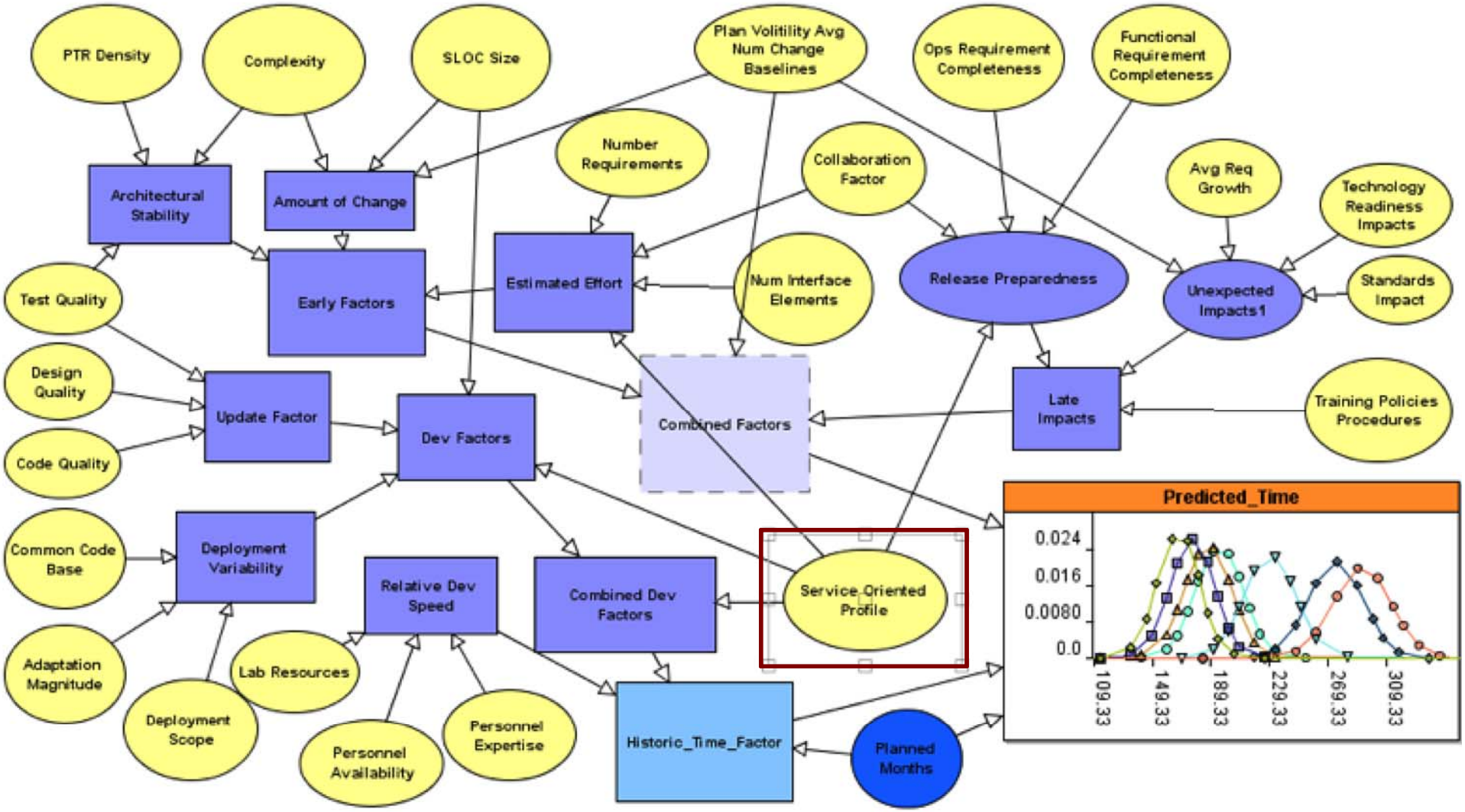
Update Solution Implementation Model



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Project A and Project B Synopsis

- Both results support the original hypothesis of this research
- Paraphrased:
  - Bayesian network models combine quantitative with qualitative expert judgment that capture and leverage causal relationships about "**Peoples' internal knowledge that is not captured externally or formally"**
- Increases the accuracy of cost and schedule predictions
- Programs have used to predict future releases

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Risk Relationship Models for Benefit/Performance Tradeoff Analysis

- Demonstrate a collaborative way to have various stakeholders understand common and divergent beliefs about program/portfolio/enterprise/capability factors that lead to risk or could be changed to mitigate risks
- Created two different models
  - —Risk Relationship Risk Index (RRRI)
    - Derived from analysis of research performed on FAA Enterprise and Portfolio Risks
  - —Market Stability Index Risk
    - Derived from combination of factors in other models and key factors derived from data and discussions with Ron Stroup (and others)
- Have applied to some scenarios
  - —Impacts on funding for ADS-B In Op. Trials, 28-Sep-2012, Ronald L. Stroup
  - —GBAS and ILS tradeoff

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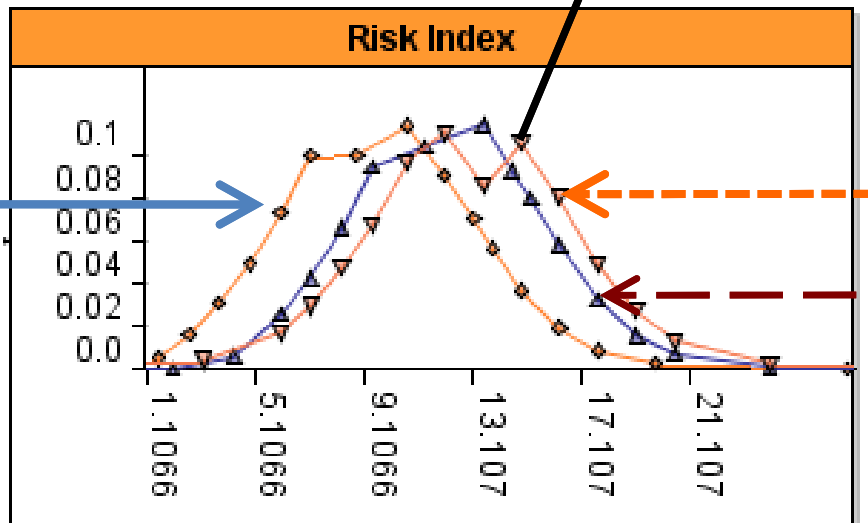
Quantifies Risk: Map Probabilistic Risk to Risk Matrix

Risk Matrix							
Likelihood	Near Certainty	E	5	13	20	22	25
	Highly Likely	D	4	12	15	21	24
	Likely	C	3	11	14	17	23
	Low Likelihood	B	2	7	9	16	19
	Not Likely	A	1	6	8	10	18
			1	2	3	4	5
			Very Low	Low	Moderate	High	Very High
			Impact				



Actual risk region depends on Impact vs. Likelihood

Operational Improvement Risk Scenarios	Mean
ADS-B In (person 1)	9.7
GBAS and ILS (Two SME teaming to answer factors)	12.3
ADS-B In (person 2)	13.5

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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
- 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 are developing and refining a modeling and analysis framework to enable a **process for managing decision-making**
  - —Approach will improve the accuracy of schedule and cost predictions (and reduce the variance)
- **Models working sufficiently well that we're transferring models to FAA**

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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 and Cindy Adamskyj 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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Thank You

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