Results from Applying a Modeling and Analysis Framework to an FAA NextGen System of Systems Program
Presented to: SoSECIE 2014
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Dr. Art Pyster
Dr. Robin Dillon-Merrill
Dr. Teresa Zigh
Dr. Richard Turner
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**
Risk-Informed Decision-Making: Leveraging What People Know in Changing Contexts

- Need: improve **collaboration** across SoS and disciplines
  - NextGen is a complex SoS and rolling out capabilities is challenging due to:
    - Many factors
    - Complex interdependencies and asynchronous integration
    - Diverse set of stakeholders

- Objective: develop 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

- Approach: use Bayesian networks to combine quantitative with qualitative expert judgment to capture and leverage causal relationships about **“Peoples’ internal knowledge that is not captured externally or formally”**
What is the FAA NextGen?
NextGen Vision of Integrated Framework of SoS Operations

Cross-Cutting Factors
- Environmental
- Safety
- Information Security
- Economic
- International
- Regulation

Legend:
- Private Sector
- FAA (USG)
- Local entities

Enablers
- People
- Procedures
- Technology
- Data/Information
- Policy

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)
Example Implementation Portfolio From NextGen Implementation Plan

Portfolio (1 of 10)

www.faa.gov/NextGen

Timelines:

- Operational Improvement Increment
- Operational Improvement

What’s the Probability (Risk) of finishing at this point in time?
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

1) Program Releases or
2) Operational Improvement Candidates or
3) Risk Scenarios

Modeling Framework for Decision Making at Portfolio & Enterprise Levels

- Quantitative
- Qualitative factors

- Cost, Schedule, & Benefit predictions
- Risk calculations
- Factor impacts on practices
- Aligns with FAA Acquisition Management System (AMS)

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• 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
Developed Models to Support Decision Making for FAA AMS

FAA LIFECYCLE MANAGEMENT PROCESS

FAA Terms
- Concept & Requirements Definition (CRD)
- Investment Analysis (IA)
- Final Investment Decision (FID)
- NextGen Segment Implementation Plan (NSIP)

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

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Four Types of Models Predict Risks Based on *Internal Knowledge Not Captured Externally or Formally*

1) Improve Collaborative Decision-Making for CRD & IA supporting NSIP Evolution

Model being applied to NSIP 2014

Example:
- Three SME inputs illustrate difference in schedule of ~7 months based on different beliefs in factors for Improved Surface Operations

Maps to a Quantification of Risk

Concept applied to
- ADS-B In
- GBAS and ILS

2) Improve Prediction of Schedule and Cost in Solution Implementations

3) Improve Collaborative Decision-Making About Systemic Risks and Benefits

4) Improve Risk-Informed Decision Making for NextGen Benefits due to Market Stability
Model Aligns Primarily with CRD and Investment Analysis Aspects of FAA AMS

FAA Acquisition Management System

- Mission Analysis
- Concept & Requirements Definition (CRD) and Investment Analysis (IA)
- Solution Implementation (SI)

Enterprise Risk Management

- Model Service
- Model CRD & IA
- Model - SI

Analysis and Modeling Framework

We Are Here
Objective for CRD and IA Models – Moving OIIIs 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?
Example Implementation Portfolio From NextGen Implementation Plan

Portfolio (1 of 10)

www.faa.gov/NextGen

Timelines:
Operational Improvement Increment

Operational Improvement

What’s the Probability (Risk) of finishing at this point in time?

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

<table>
<thead>
<tr>
<th>Operational Improvement Increments</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Situational Awareness and Alerting of Ground Vehicles</td>
<td>27.4</td>
</tr>
<tr>
<td></td>
<td>32.0</td>
</tr>
<tr>
<td></td>
<td>34.6</td>
</tr>
</tbody>
</table>
Time-Based Flow Management Portfolio Example

- Maximum difference more than 8 months for Operational Improvement

<table>
<thead>
<tr>
<th>Operational Improvement Increments</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extended Metering</td>
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<tr>
<td>Arrival Interval Management Using Ground Automation</td>
<td>25.3</td>
</tr>
<tr>
<td>Use RNAV Route Data to Calculate Trajectories Used to Conduct TBM Operations</td>
<td>33.9</td>
</tr>
<tr>
<td>Integrated Departure/Arrival Capability</td>
<td>34.1</td>
</tr>
</tbody>
</table>
SMEs Use Spreadsheet Collection Instrument to Assign Factor Values to Each OII

<table>
<thead>
<tr>
<th>Portfolio</th>
<th>Operational Improvement</th>
<th>Time Point in CRD &amp; IA</th>
<th>Factors (by Category)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Operational Improvement and Increments for Portfolios</td>
<td>Starting Point Timeframe</td>
<td>Candidate Factors</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Requirement Goodness</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dependency Criteria</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Interface Impact</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Operational Readiness</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Risk Impact</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Emerge Impact</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Collaborative Air Traffic Management Portfolio (DP 19 WP 2, 199 - WP 3)</th>
<th>Pick</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic Management Initiatives with Flight-Specific Trajectories (105208)</td>
<td>4</td>
<td>Med</td>
</tr>
<tr>
<td>105208-11 Execution of Flow Strategies</td>
<td>0</td>
<td>Low</td>
</tr>
<tr>
<td>105208-12 Delivery of Pre-Departure Reroutes to Controllers</td>
<td>0</td>
<td>Low</td>
</tr>
<tr>
<td>Continuous Flight Day Evaluation (105302)</td>
<td>2</td>
<td>Low</td>
</tr>
<tr>
<td>105302-12 Enhanced Congestion Prediction</td>
<td>4</td>
<td>High</td>
</tr>
<tr>
<td>105302-11 Collaborative Airspace Constraint Resolution (CACR)</td>
<td>3</td>
<td>Med</td>
</tr>
<tr>
<td>Provide Full Flight Plan Constraint Evaluation with Feedback (101102)</td>
<td>5</td>
<td>High</td>
</tr>
<tr>
<td>101102-11 Collaborative Trajectory Options Program (CTOP)</td>
<td>0</td>
<td>Low</td>
</tr>
<tr>
<td>101102-12 Route Availability Planning</td>
<td>2</td>
<td>Pick</td>
</tr>
<tr>
<td>Improved Surface Operations Portfolio</td>
<td>Pick</td>
<td>Pick</td>
</tr>
<tr>
<td>Provide Full Surface Situation Information (102406)</td>
<td>0</td>
<td>Pick</td>
</tr>
<tr>
<td>102406-11 Situational Awareness and Alerting of Ground Vehicles</td>
<td>4</td>
<td>Pick</td>
</tr>
</tbody>
</table>

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

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### Collection Spreadsheet has Factor Guidelines on Factors-Meaning Definition Worksheet

<table>
<thead>
<tr>
<th>Factor Category</th>
<th>Factors</th>
<th>General: These factors should apply to most Operational improvements that are Pre-implementation.</th>
<th>Ranking Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requirement maturity and stability</td>
<td>- 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).</td>
<td></td>
<td>H - Best M - Medium L - Worst (negative impact)</td>
</tr>
<tr>
<td>Sequence Diagram Completeness</td>
<td>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).</td>
<td></td>
<td>H - Best M - Medium L - Worst (negative impact)</td>
</tr>
<tr>
<td>Function Rqmts Completeness</td>
<td>- 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).</td>
<td></td>
<td>H - Best M - Medium L - Worst (negative impact)</td>
</tr>
<tr>
<td>Requirement goodness</td>
<td>```</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operational Rqmts Completeness</td>
<td>If Sequence Diagrams are used and they are complete, it is likely that the Operational Requirements will align with the same factor rating.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interdependencies</td>
<td>- 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).</td>
<td></td>
<td>L - Best M - Medium H - Worst (negative impact)</td>
</tr>
<tr>
<td>Legacy Dependencies</td>
<td>- if there are a large number (relative, but could be &gt; 3) of Legacy Dependencies (and/legacy components) then High (H), - if the capability has no interdependencies the Low (L), - otherwise Medium (M)</td>
<td></td>
<td>L - Best M - Medium H - Worst (negative impact)</td>
</tr>
<tr>
<td>Dependency criteria</td>
<td>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).</td>
<td></td>
<td>L - Best M - Medium H - Worst (negative impact)</td>
</tr>
<tr>
<td>Integration Impact</td>
<td>- 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).</td>
<td></td>
<td>L - Best M - Medium H - Worst (negative impact)</td>
</tr>
</tbody>
</table>
Approach: Developed Models Align with FAA AMS to Address Varying Lifecycle Factors

Enterprise & Portfolio Risk Management

Model Service

Model CRD & IA

Model - SI

Analysis and Modeling Framework

FAA Acquisition Management System

Mission Analysis

Concept & Requirements Definition (CRD) and Investment Analysis (IA)

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

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

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

#### Factors Categories (Next Slide for Details)

<table>
<thead>
<tr>
<th>ID</th>
<th>Plan Start Date</th>
<th>Actual Start Date</th>
<th>Planned End Date</th>
<th>SLOC Size (7)</th>
<th># of Interface Elements</th>
<th># Req/ NCPs</th>
<th>Complexity</th>
<th>PTR Density</th>
<th>PTR Closing Rate</th>
<th>Deployment Scope</th>
<th>Common Codebase (Reuse)</th>
<th>Adaptation Magnitude</th>
<th>Operational Requirements Completeness</th>
<th>Functional Requirements Completeness</th>
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</thead>
<tbody>
<tr>
<td>RB1</td>
<td>9/4/12</td>
<td>10/17/12</td>
<td>2/20/13</td>
<td>Very Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>RB2</td>
<td>3/30/12</td>
<td>3/30/12</td>
<td>10/9/12</td>
<td>Med</td>
<td>Low</td>
<td>Low</td>
<td>Med</td>
<td>Low</td>
<td>Low</td>
<td>Med</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Med</td>
</tr>
<tr>
<td>RB4</td>
<td>7/9/12</td>
<td>7/9/12</td>
<td>11/6/12</td>
<td>Med</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Med</td>
<td>Low</td>
<td>High</td>
<td>Med</td>
</tr>
<tr>
<td>RB6</td>
<td>7/9/12</td>
<td>7/9/12</td>
<td>12/13/12</td>
<td>Med</td>
<td>High</td>
<td>Med</td>
<td>Med</td>
<td>Med</td>
<td>Med</td>
<td>Low</td>
<td>Low</td>
<td>Med</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>RB10</td>
<td>8/16/12</td>
<td>8/16/12</td>
<td>3/15/13</td>
<td>Very Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>RB11</td>
<td>11/26/12</td>
<td>12/6/12</td>
<td>3/27/13</td>
<td>Very Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>
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.
Summary Data for Cost Prediction/Estimation
Releases R17 – R22 – Planned vs. Predicted

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

% Diff Predict

Plan

Mean Predicted

Planned Duration Time (days)
## Analysis of Solution Implementation Model

<table>
<thead>
<tr>
<th>Questions</th>
<th>Answer</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Were there missing factors?</td>
<td>Yes</td>
<td><strong>Service Oriented Computing</strong> was the only new factor, and might apply to other Solution Implementation programs</td>
</tr>
<tr>
<td>Do the same factors apply to both systems in the solution implementation phase?</td>
<td>Yes</td>
<td>Added Service Orientation of Program and adjusted some causal relationships</td>
</tr>
<tr>
<td>Are the causal relationships between factors the same?</td>
<td>No</td>
<td>Changed some causal relationships related to Service Orientation Factor which reduce impact of <strong>Deployment Factor, Operational Requirements</strong>, increases impact of <strong>Number of Interfaces</strong></td>
</tr>
<tr>
<td>Are the factor weightings the same?</td>
<td>Yes</td>
<td>Adjusted to some of the weighting</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>See model on next slide</strong></td>
</tr>
</tbody>
</table>

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Updated Solution Implementation Model
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 developed and refined a modeling and analysis framework to enable a process for managing risk-informed decision-making
  — Approach improves the accuracy of schedule and cost predictions (and reduce the variance)

• Models working sufficiently well that we transferred models and guidebook for updating models to FAA
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.
• For more information contact:
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   — Mark.Blackburn@stevens.edu
   — 703.431.4463
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)
    o Derived from analysis of research performed on FAA Enterprise and Portfolio Risks
  — Market Stability Index Risk
    o 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
Quantifies Risk: Map Probabilistic Risk to Risk Matrix

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Near Certainty</th>
<th>Highly Likely</th>
<th>Likely</th>
<th>Low Likelihood</th>
<th>Not Likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>5</td>
<td>13</td>
<td>20</td>
<td>22</td>
<td>25</td>
</tr>
<tr>
<td>D</td>
<td>4</td>
<td>12</td>
<td>16</td>
<td>21</td>
<td>24</td>
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<tr>
<td>C</td>
<td>3</td>
<td>11</td>
<td>14</td>
<td>17</td>
<td>23</td>
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<td>B</td>
<td>2</td>
<td>7</td>
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<td>16</td>
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<td>A</td>
<td>1</td>
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<td>8</td>
<td>12</td>
<td>18</td>
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</table>

<table>
<thead>
<tr>
<th>Impact</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

- Actual risk region depends on Impact vs. Likelihood

**Operational Improvement Risk Scenarios**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADS-B In (person 1)</td>
<td>9.7</td>
</tr>
<tr>
<td>GBAS and ILS (Two SME teaming to answer factors)</td>
<td>12.3</td>
</tr>
<tr>
<td>ADS-B In (person 2)</td>
<td>13.5</td>
</tr>
</tbody>
</table>