A Risk-Based Decision Support Tool for Evaluating Aviation Technology Integration in the National Airspace System

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Outline

- Background
- Safety Risk Management
  - Human Factors Analysis and Classification System (HFACS)
  - Aviation System Risk Model (ASRM)
- ASRM Prototype
- Concluding Remarks
University/Industry Team Approach

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- Ms. Huda Hadi, ISE junior (RU Undergraduate Research Fellow)
- Ms. Cara Lee, ISE junior
“Safety itself is an internal construct, a concept and not a measurable quantity or any objective attribute of a structure...

Safety is inevitably a judgment that cannot be proven true by any method of deductive logic.

Safety resides in belief, and when we say that a structure is safe, this means we hold some sufficient degree of belief that it is” (p. 257).
Aviation Safety Strategies

**Vehicle Safety Technologies**
- Make every flight the equivalent of clear-day operations
- Self-healing designs and “refuse-to-crash” aircraft
- Increases survivability when accidents and aviation fires occur

**Weather Safety Technologies**
- Brings intelligent weather decision-making to every cockpit
- Eliminate icing as an aviation hazard

**System Safety Technologies**
- Monitor and assess all data from every flight for known & unknown issues
- Improves human/machine integration in design, operations, & maintenance
- Applies aerospace technology to search and rescue needs

*Source: Frank Jones, Technical Integration Lead, Rutgers University, April 30, 2003*
Research Objective

**Decision Support to Evaluate Technology Insertion**

- Research Objective -

- Provide a prototype capability that demonstrates the effectiveness of risk mitigation strategies, such as technology insertions / interventions in the National Airspace System (NAS).

The primary cause of aviation accidents is aircraft striking the ground.

- U.S. Army
~ 1920
Influence Diagram

Decision Nodes

Directed Causal Link

Chance Nodes
Aviation System Risk Model (ASRM)

Reason Socio-Technical Framework

Organizational  Task/Environmental  Individual  Consequence

Influence Diagram

- Org_Process
- Org_Climate
- Resource_Mgmt
- Transport_Canada
- Adverse Mental...
- Inadequate Super...
- Failure To Com...
- Planned_Inapp...
- Supervisory Mol...
- CRM
- Decision Errors
- Perceptual Errors
- Routine Violations
- Weather
- Loss of Control
Relative Risk “Intensity”

Causal Factors

Likelihood

Technology Insertions / Interventions
Analytical Modeling Approach

Analytical Approach

Describe Case-Based Scenario → Identify Causal Factors → Construct Influence Diagram

Build Belief Network → Technology/Interventions → Assess Relative Risk
# Maintenance Case Study

<table>
<thead>
<tr>
<th>Case</th>
<th>Descriptor</th>
<th>Main Features</th>
<th>Possible Technology Insertions</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Airlines Flight 811</td>
<td>Explosive decompression – loss of cargo door in flight.</td>
<td>No documentation or training on the use of view ports</td>
<td>AM 4 SAAP 1 SWAP 1, 6, 7, 8, 9 (as determined by subject matter experts)</td>
</tr>
<tr>
<td>Boeing 747-122</td>
<td></td>
<td>UAL’s trend analysis program did not indicate the cargo door rigging problems</td>
<td></td>
</tr>
<tr>
<td>Honolulu, HI, Feb 24, 1989</td>
<td></td>
<td>FAA’s delayed action to issue AD-88-12-04</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>UAL’s maintenance manual differs from Boeing’s manual</td>
<td></td>
</tr>
</tbody>
</table>

# Causal Factors

## Case-Specific Contributing Factors

<table>
<thead>
<tr>
<th>HFACS-ME Factors</th>
<th>Organizational</th>
<th>Task / Environmental</th>
<th>Individual</th>
</tr>
</thead>
</table>
| • Inadequate Documentation  
  • Inadequate Design  
  • Uncorrected Problem  
  • Inadequate Supervision  
  • Judgment / Decision Making | • Training/ Preparation  
  • Unavailable / Inappropriate Equipment  
  • Dated / Uncertified Equipment | • Skill / Technique Based |
| Non-HFACS-ME Factors | • FAA-Certification  
  • FAA-Oversight  
  • FAA-Inadequate Resources  
  • UAL-Inappropriate Processes  
  • FAA/Boeing Insufficient timeliness of corrective guidance | | • Improper Inspection |
Causal Factor Interactions

Organizational  Task/Environmental  Individual  Consequence

Judgement/Decision...
Uncorrected Problem
Skill/Technique Based

Dated/Uncertified E...

Inadequate superv...

Inadequate document...

Inadequate design

UAL Inappropriate P...

Unavailable/Inapprop...

Training/Preparation

FAA oversight

FAA Inadequate Res...

FAA Certification

FAA Boeing Insuffici...

Improper Inspection

Structural Failure
ASRM Prototype

Aviation System Risk Model (ASRM)
Prototype Version 1.0

Organizational Factors | Task & Environmental Factors | Individual Factors | Consequence | Relative Risk Intensity
--- | --- | --- | --- | ---

Principal Investigator:
Dr. James T. Luxhøj
Software Developer:
Muhammad N. Jalil

NASA Langley Research Center
Hampton, VA
ASRM Model Library

Aviation System Risk Model
Model Library

- Aviation System Risk Model - Loss of Control in Flight (LOC)
- Aviation System Risk Model - Maintenance (Main)
- Aviation System Risk Model - Controlled Flight into Terrain (CFIT)
- Runway Incursion (RI)
- Weather (Wx)

Select

Continue  End

Accident Synopsis
MAINTENANCE CASE STUDY 1:

ASRM Maintenance case study 1 is based on the United Airlines Flight 811 accident that occurred on February 24, 1989. This accident occurred due to in-flight separation of the forward lobe cargo door followed by explosive decompression leading to loss of control during flight.

The airplane made a successful emergency landing at Honolulu, and the passengers evacuated the airplane. Nine of the
AvSP Technology Insertions

Scenarios: Combinations of technologies/interventions

AvSP Products
Virtual Reality Technology for Aircraft Visual Inspection

To develop prototypes for augmented-reality displays for maintenance aiding

Example
Developed a virtual environment of an aircraft cargo bay of an L1011 aircraft for real-time inspection simulation (hosted on a head-mounted display)
Incorporated Virtual Reality (VR) capabilities to study human performance

- Binocular eye movements are tracked and recorded in VR
- Recorded eye movements (scan paths) and fixations are visualized off-line following immersion for purposes of analysis and training recommendations

Created defect scenarios allowing trainers to select defect patterns in virtual environment (e.g., no defects, simulated cracks, conduit damage, corrosion, ...)

Visualization of gaze in virtual environment
(Inside the cargo bay area)

Source: http://avsp.larc.nasa.gov/images_swap_VRtech.html
## Initial Risk Assessment Findings

<table>
<thead>
<tr>
<th>Scenario Description</th>
<th>Targeted Causal Factor(s)</th>
<th>Technology Element(s) Inserted</th>
<th>Risk (Factors)</th>
<th>Relative % Decrease or (Increase) on Factors</th>
<th>Risk (Consequence)</th>
<th>Relative % Decrease or (Increase) on Consequence</th>
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</thead>
<tbody>
<tr>
<td>Baseline Scenario</td>
<td>-</td>
<td>None</td>
<td>-</td>
<td>-</td>
<td>26%</td>
<td></td>
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<tr>
<td>Maintenance Scenario No. 1</td>
<td>Inadequate Design</td>
<td>AM-4</td>
<td>14%</td>
<td>49%</td>
<td>23%</td>
<td>11%</td>
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<tr>
<td></td>
<td>FAA Certification</td>
<td>SWAP- 1</td>
<td>15%</td>
<td>49%</td>
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<td></td>
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<tr>
<td></td>
<td>FAA Oversight</td>
<td>SWAP- 8</td>
<td>22%</td>
<td>21%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Judgment Decision Making</td>
<td></td>
<td>22%</td>
<td>17%</td>
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<tr>
<td>Maintenance Scenario No. 3</td>
<td>FAA Certification</td>
<td>SWAP - 1</td>
<td>21%</td>
<td>27%</td>
<td>23.1%</td>
<td>12%</td>
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<td></td>
<td>FAA Oversight</td>
<td>SWAP - 9</td>
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<td>31%</td>
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<td>SWAP - 8</td>
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<td>20%</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>17%</td>
<td>37%</td>
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<tr>
<td></td>
<td>Inadequate Supervision</td>
<td></td>
<td>21%</td>
<td>25%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FAA Inadequate Resources</td>
<td></td>
<td>20%</td>
<td>26%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inadequate Design</td>
<td></td>
<td>17%</td>
<td>42%</td>
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<tr>
<td></td>
<td>Skill / Technique Based</td>
<td></td>
<td>22%</td>
<td>15%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Improper Inspection</td>
<td></td>
<td></td>
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<tr>
<td>Maintenance Scenario No. 5</td>
<td>FAA Certification</td>
<td>SWAP - 8</td>
<td>20%</td>
<td>32%</td>
<td>23%</td>
<td>11%</td>
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<tr>
<td></td>
<td>FAA Oversight</td>
<td>SAAP - 1</td>
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<tr>
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<td>Judgment Decision Making</td>
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<td>29%</td>
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<tr>
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<tr>
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<td>Skill / Technique Based</td>
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<td>19%</td>
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<tr>
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<td>Improper Inspection</td>
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<td>22%</td>
<td>14%</td>
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</table>

**Causal Factors**

**Consequence**
### ASRM - Executive Summary

<table>
<thead>
<tr>
<th>Relative Risk Intensity Decrease (Increase)</th>
<th>Consequence</th>
<th>11%</th>
<th>12%</th>
<th>15%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model/Scenario Number</td>
<td>MAIN 1-S1</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>MAIN 1 - S3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MAIN 2 - S1</td>
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</tr>
</tbody>
</table>

**Selection of “Best” Scenarios**

“drill down” to scenario details
Case Study Research

- **Analytic Generalization** - not statistical sampling, but generalizing findings to theory (i.e. *replication logic*, see Yin, 1994, 2003; Rasmussen, 1993)

- **Case Study research quality:**
  - construct validity
  - internal validity
  - external validity
  - reliability
Multiple Sources for Belief Assessments

“Beliefs” FAA Aviation Safety Inspectors (ASIs), “Reviews” by NASA Level 2/Level 3 Managers

Organizational Factors Survey Data

“Beliefs” from FAA Aviation Safety Inspectors (ASIs)

HFACS data

NTSB/NASDAC data

ASAFE Event Tree Conditional Probabilities

Overall Models reviewed by Expert Advisory Panel
Concluding Remarks

• The ASRM provides an *analytical framework* for incorporating *both data and expert judgments* for projecting system risk and evaluating the impact of technology insertions/interventions.

• The *integration* of HFACS (initially) and the ASRM provides a unique analytical method/tool for commercial aviation. Eventually, other data sources will be included.