The Challenges of a Quantitative Approach to Risk Assessment

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Purpose and Contribution

• Nature and complexity of quantifying risk assessment
• Guidance to system safety practitioners for quantifying risk assessment according to MIL-STD-882E (Department of Defense Standard Practice System Safety)
• Multi-Relational Risk Assessment Model (MRRAM)
Outline

• Risk Assessment Literature
• Motivation and Significance
• Risk Assessment in MIL-STD-882
• The Multi-Relational Risk Assessment Model (MRRAM)
• MRRAM Case Study
• Conclusions
Risk Assessment Literature

• Methodology to address uncertainty with respect to aircraft crashes (Alexander, 1996)

• Hazard risk index to represent the cumulative risk of all the hazards (Andrews, 2004)

• Numeric inputs and outputs of probabilistic analyses to represent uncertainty (Cooper, 2004)

• Composite risk index based on the human perception of equivalent risk (Banerjee, 2011)

• Multiple severity method to determine mishap risk in terms of monetary units (Taubel, 2011)
Motivation and Significance

• Motivation (gap in literature)
  – Lack of mishap risk modeling (mishap severity and mishap probability)
  – Unclear hazard-mishap relationship in the models
  – Modeled severity or probability of hazard to quantify risk

• Significance
  – Collective assessment of risk using the multitude of severity/probability cases to assess "total" risk
  – Hazards-mishaps-effects (environment) relationship
Risk Assessment in MIL-STD-882

- **1977**
  - MIL-STD-882A
  - Hazard Probability
  - Categories for frequency of occurrence

- **1984**
  - MIL-STD-882B
  - Risk
  - Hazard Severity
  - Hazard Prob.
  - Mishap

- **1993**
  - MIL-STD-882C
  - Risk
  - Hazard Severity
  - Hazard Prob.
  - Mishap Impact

- **2000**
  - MIL-STD-882D
  - Mishap Risk
  - Mishap Severity
  - Mishap Prob.

- **2012**
  - MIL-STD-882E
  - RACs
  - Mishap Severity
  - Mishap Prob.
  - Risk Levels

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Risk Assessment in MIL-STD-882 (Cont’d)

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- Hazard Probability
- Categories for frequency of occurrence

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- Hazard Prob.
- Mishap

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- Risk
- Hazard Severity
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- Mishap Impact

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    - Hazard Prob.
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- Risk Levels

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System Safety Process in MIL-STD-882E

Element 1: Document the System Safety Approach

Element 2: Identify and Document Hazards

Element 3: Assess and Document Risk (Highlighted)

Element 4: Identify and Document Risk Mitigation Measures

Element 5: Reduce Risk

Element 6: Verify, Validate and Document Risk Reduction

Element 7: Accept Risk and Document

Element 8: Manage Life-Cycle Risk
# Mishap Severity

<table>
<thead>
<tr>
<th>Description</th>
<th>Severity Category</th>
<th>Mishap Result Criteria</th>
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<tbody>
<tr>
<td></td>
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<td>Personnel Injury</td>
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<tr>
<td>Catastrophic</td>
<td>1</td>
<td>Death, permanent total disability</td>
</tr>
<tr>
<td>Critical</td>
<td>2</td>
<td>Permanent partial disability, injuries or occupational illness that may result in hospitalization of at least three personnel</td>
</tr>
<tr>
<td>Marginal</td>
<td>3</td>
<td>Injury or occupational illness resulting in one or more lost work day(s)</td>
</tr>
<tr>
<td>Negligible</td>
<td>4</td>
<td>Injury or occupational illness not resulting in a lost work day</td>
</tr>
</tbody>
</table>

“To determine the appropriate severity category as defined in Table I for a given hazard at a given point in time, identify the potential for death or injury, environmental impact, or monetary loss. A given hazard may have the potential to affect one or all of these three areas.”
Mishap Probability

“To determine the appropriate probability level as defined in Table II for a given hazard at a given point in time, assess the likelihood of occurrence of a mishap.”

**TABLE II. Probability levels**

<table>
<thead>
<tr>
<th>Description</th>
<th>Level</th>
<th>Specific Individual Item</th>
<th>Fleet or Inventory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequent</td>
<td>A</td>
<td>Likely to occur often in the life of an item.</td>
<td>Continuously experienced.</td>
</tr>
<tr>
<td>Probable</td>
<td>B</td>
<td>Will occur several times in the life of an item.</td>
<td>Will occur frequently.</td>
</tr>
<tr>
<td>Occasional</td>
<td>C</td>
<td>Likely to occur sometime in the life of an item.</td>
<td>Will occur several times.</td>
</tr>
<tr>
<td>Remote</td>
<td>D</td>
<td>Unlikely, but possible to occur in the life of an item.</td>
<td>Unlikely, but can reasonably be expected to occur.</td>
</tr>
<tr>
<td>Improbable</td>
<td>E</td>
<td>So unlikely, it can be assumed occurrence may not be experienced in the life of an item.</td>
<td>Unlikely to occur, but possible.</td>
</tr>
<tr>
<td>Eliminated</td>
<td>F</td>
<td>Incapable of occurrence. This level is used when potential hazards are identified and later eliminated.</td>
<td>Incapable of occurrence. This level is used when potential hazards are identified and later eliminated.</td>
</tr>
</tbody>
</table>
Mishap “Environment”

• As the environment is defined, the likelihood of mishap occurrence within that environment must be described.
  – Slip/fall on ice vs. dry conditions
• Typical events such as developmental or operational testing, demonstrations, and fielding should help the system safety practitioner define the environment where the mishap is likely to occur.
Risk Assessment Matrix (MIL-STD-882E)

<table>
<thead>
<tr>
<th>SEVERITY</th>
<th>Catastrophic (1)</th>
<th>Critical (2)</th>
<th>Marginal (3)</th>
<th>Negligible (4)</th>
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</thead>
<tbody>
<tr>
<td>Frequent (A)</td>
<td>High</td>
<td>High</td>
<td>Serious</td>
<td>Medium</td>
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<tr>
<td>Probable (B)</td>
<td>High</td>
<td>High</td>
<td>Serious</td>
<td>Medium</td>
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<tr>
<td>Occasional (C)</td>
<td>High</td>
<td>Serious</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Remote (D)</td>
<td>Serious</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Improbable (E)</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
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<tr>
<td>Eliminated (F)</td>
<td>Eliminated</td>
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</tbody>
</table>

Element 1: Document the System Safety Approach
Element 2: Identify and Document Hazards
Element 3: Assess and Document Risk
Element 4: Identify and Document Risk Mitigation Measures
Element 5: Reduce Risk
Element 6: Verify, Validate and Document Risk Reduction
Element 7: Accept Risk and Document
Element 8: Manage Life-Cycle Risk

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The Multi-Relational Risk Assessment Model (MRRAM)

• Mathematical representation of the multi-relational relationship between hazards, mishaps, environment, and effects based on MIL-STD-882E

• Guidance approach to system safety practitioners for quantifying “total risk” assessment
MRRAM Assumptions

• Causal factors considered but not modeled
• Finite number of independent but not mutually exclusive hazards
• Probability of a mishap based on contributing hazards (set of hazards)
• Mishap independent effects in terms of personnel injury, equipment damage/loss, and environment damage
Causal Factor-Hazard-Mishap

One-to-one

Mishap (M) → Hazard (H)

Hazard (H) → Causal Factor (CF)

Many-to-many

Mishap (1) → Hazard (1)
Mishap (2) → Hazard (2)
... → Hazard (H)

Causal Factor (1) → Hazard (1)
Causal Factor (2) → Hazard (2)
... → Causal Factor (CF)

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MRRAM Framework

Personnel Injury

Equipment Damage

Environment Damage

Mishap Environment

Set of Hazards

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MRRAM Case Study

Personnel Injury  Equipment Damage  Environment Damage

Hazards:
- Unskilled Driver
- Excessive Speed
- Distracted Driver
- Bad Weather
- Bad Roads

Effects:

Car Crash into Shallow Lake or Pond

Car near lake or pond

Personnel Injury  Equipment Damage  Environment Damage

Hazards:
- Unskilled Driver
- Excessive Speed
- Distracted Driver
- Bad Weather
- Bad Roads

Effects:

10/16/2014

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Car Crash into Heavy Immobile Object

Personnel Injury

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Equipment Damage

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Environment Damage

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Hazards:
- Unskilled Driver: \( P_{UD} \)
- Excessive Speed: \( P_{ES} \)
- Distracted Driver: \( P_{DD} \)
- Bad Weather: \( P_{BW} \)
- Bad Roads: \( P_{BR} \)

Environment:
- Car near heavy immovable object
Personnel Injury  
Equipment Damage  
Environment Damage

Car Crash into Light & Movable Object

Unskilled Driver: $P_{UD}$  
Excessive Speed: $P_{ES}$  
Distracted Driver: $P_{DD}$  
Bad Weather: $P_{BW}$  
Bad Roads: $P_{BR}$
Mishap: Car Crash

Environment: Near shallow lake

Personnel Injury

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Hazards

- Unskilled Driver
- Excessive Speed
- Distracted Driver
- Bad Weather
- Bad Roads
Mishap: Car Crash

Environment: Near shallow lake

Personnel Injury

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Hazards

- Unskilled Driver
- Excessive Speed
- Distracted Driver
- Bad Weather
- Bad Roads

Effects

- Personnel Injury
- Equipment Damage
- Environment Damage
Hazards Combinations
Example

- What is the probability that an unskilled driver (hazard) crashes a car (mishap) into a shallow lake (environment) causing a major injury (mishap result criterion) to personnel (effect)?
Mishap: Car Crash

Environment: Near shallow lake

Personnel Injury

Equipment Damage

Environment Damage

Personnel Injury:
- A
- B
- C
- D
- E

Equipment Damage:
- A
- B
- C
- D
- E

Environment Damage:
- A
- B
- C
- D
- E

Hazards:
- Unskilled Driver
- Excessive Speed
- Distracted Driver
- Bad Weather
- Bad Roads
Conclusions

• The Challenges of a Quantitative Approach to Risk Assessment
  – Safety programs rarely capture data to obtain the probability estimate of a mishap for a hazard.
  
  – Appropriate and representative quantitative data hardly exists.
  
  – The complex nature of the multi-relation of hazards, mishaps, and effects leads system safety practitioners towards a qualitative risk assessment analysis approach.
Conclusions (Cont’d)

– Assess total risk based on all effects within an environment.

– More emphasis is needed to study and understand the underlying assumptions of existing quantitative risk assessment.

– System safety practitioners should consider “return on investment” to their programs before delving into risk assessment quantification.
References

Questions