Incident and Accident Metrics

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The challenge of small numbers

• How do you measure safety for a single airline?
• Which safety metrics are appropriate?
• How do you determine your airline’s most likely accident?
• How can you quantify the effectiveness of risk mitigation measures before implementing them?

Source: Boeing, Statistical Summary of Commercial Jet Airplane Accidents
Background

Mission Statement

- Predicting statistically valid accident probabilities for an individual airline based on available evidence from accident free operation.

- Accounting for airline-specific factors such as operations, training, etc.

Predictive Analysis:
Making quantitative statements about the future state based on previous experience and knowledge.

BUT: How to implement Predictive Analysis for practical application?
Solution?

Classical statistical approach

\[ P_{\text{Incident}} = \frac{\text{Frequency of Incident} \times}{\text{Number of Flights}} \]

Runway overrun example

\[ P_{\text{Incident}} = \frac{0}{400\,000} = 0 \]

Simple statistical approach is inappropriate and **unsuitable for rare events**

*Serious incidents* as defined in ICAO Annex 13
Basic Hypothesis

Predictive Analysis:
Making quantitative statements about the future state based on:
- previous experience
- knowledge

- previous experience = data/evidence driven
  - recorded data
  - known accident types and their causes

- knowledge
  - physical relation between contributing factors and accident
  - known cause-consequence-chains

Basic Hypothesis:
1. Accidents cannot be directly observed in daily operation, however, the contributing factors still occur at high frequency so they can be measured or observed with statistical significance.
2. The relation between the contributing factors and the accident can be described by the laws of physics and cause-consequence-chains based on operational and procedural knowledge.
Predictive Analysis Concept

- Unknown Contributing Factors
- Contributing Factors
- Advanced Statistical Methods
- Physical Model
- Incident
Predictive Analysis on Runway Overrun

Contributing Factors (Model Input)

- Weight
- Wind
- Speed
- Flaps
- Start of Braking
- ...

Incident Model

Overrun

Model Output

Incident Probability i.e. “Overrun”

Frequency

Transition Probabilities

Potential Outcomes

- Outcome 1 (e.g. hull loss)
- Outcome 2
- Outcome 3
- ...
- Outcome n

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Predictive Analysis on Runway Overrun

Step 1 Incident metric

Runway overrun: Stop margin < 0

Step 2 Functional relationships between contributing factors:

- Physical relationships

  \[
  (u_k)^{EB} = \frac{1}{m} \left[ -m \cdot g \cdot \sin \theta + \frac{\rho}{2} \cdot (V_A)^2 \cdot S \cdot (-\cos \beta_A \cdot C_D - \cos \beta_A \cdot \sin \beta_A \cdot C_Q) + (X_P)^B + \mu \cdot \left( -m \cdot g \cdot \cos \Theta \cdot \cos \Phi - \frac{\rho}{2} \cdot (V_A)^2 \cdot S \cdot (-C_L) \right) \right]
  \]

- Operational relationships

  Runway Condition
  - DRY
  - WET

  Procedures
  - AUTO/BRK
  - A5 RQMD
  - B

  Note: If on very long runways, it is anticipated that braking will not be sufficient, use of automatics...

  A/BRK Selection
  - OFF
  - LO
  - MED

Aerodynamics + Propulsion + Brakes + Gravitation

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Incident Model – Cause-Consequence Chains

- Reverser
- Hydraulics
- A/SKID
- ...

System Failures

- Runway Slope
- Contaminated RWY
- Tailwind
- ...

Human Factor

- No Go-around performed
- Over speed
- Check failed
- ...

Environment

- Incident 1
- Incident 2
- Incident 3
- ...

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### Cause-Consequence Chain Examples

**Contaminated Rwy**
\[ p = 2.0 \times 10^{-4} \]

**Brakes Inoperative**
\[ p = 6.4 \times 10^{-9} / \text{flight} \]

**A/SKID Fault**
\[ p = 5.6 \times 10^{-4} / \text{flight} \]

**Dual BSCU Fault**
\[ p = 6.8 \times 10^{-6} / \text{flight} \]

**Tailwind not in limits**
\[ p = 2.3 \times 10^{-5} / \text{flight} \]

**Speed not in limits**
\[ p = 2.9 \times 10^{-2} / \text{flight} \]

**Recognition Failed**
\[ p = 5.0 \times 10^{-1} / \text{flight} \]

**No Go-Around**
\[ p = 9.0 \times 10^{-1} / \text{flight} \]

**Reduced Braking Capability**

**High Energy at Touchdown**

**Incident Model**

**Overrun**

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<table>
<thead>
<tr>
<th>Cause-Consequence Chain</th>
<th>Chain Probability</th>
<th>Rank Chain</th>
<th>Incident Probability</th>
<th>Total Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chain 1</td>
<td>(2.6 \times 10^{-2})</td>
<td>1</td>
<td>(1.1 \times 10^{-6})</td>
<td>1</td>
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<tr>
<td>Chain 2</td>
<td>(2.8 \times 10^{-4})</td>
<td>2</td>
<td>(2.4 \times 10^{-9})</td>
<td>3</td>
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<tr>
<td>Chain 3</td>
<td>(2.1 \times 10^{-5})</td>
<td>3</td>
<td>(4.0 \times 10^{-4})</td>
<td>2</td>
</tr>
<tr>
<td>Chain 4</td>
<td>(3.4 \times 10^{-9})</td>
<td>4</td>
<td>(2.3 \times 10^{-11})</td>
<td>4</td>
</tr>
<tr>
<td>Chain …</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
</tr>
</tbody>
</table>

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- **Human Performance**
- **Environment**
- **System Failures**

Numbers for illustration only!
- Asking the right question can significantly increase the information we obtain.

- Quality of statistical statements depend on how we look at the data.
• Develop algorithms to extract non-measured contributing factors

• Estimation algorithms are applied to every single flight

<table>
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<tr>
<th>Parameter Estimation Implementation during Ground Roll</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td>$C_{D,G}$</td>
</tr>
<tr>
<td>$C_{D,GS}$</td>
</tr>
<tr>
<td>$\mu_{roll}$</td>
</tr>
<tr>
<td>$\mu_{roll+brake}$</td>
</tr>
</tbody>
</table>
Proof of Match
Measured and Predicted Deceleration During Ground Roll

longitudinal acceleration (m/s²)

Predicted (model)

Measured (QAR Data)

time (45 s)
Quantifying Main Drivers

What are the **main drivers** behind the incident probabilities?

<table>
<thead>
<tr>
<th>Postholder</th>
<th>ENV</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Influencable</td>
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What are the main drivers behind the incident probabilities?

Quantify the sensitivities of the contributing factors

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**Incident Model**

Overrun

### Human (HUM) vs Maintenance (MAN) vs Operations (OPS)

<table>
<thead>
<tr>
<th>Human (HUM)</th>
<th>Maintenance (MAN)</th>
<th>Operations (OPS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Training</td>
<td>Selection</td>
<td>Fatigue</td>
</tr>
<tr>
<td>A/C Type 1</td>
<td>A/C Type 2</td>
<td>A/C Type 3</td>
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<tr>
<td>A/C Type 4</td>
<td>1,000</td>
<td>1,700</td>
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<td>A/C Type 5</td>
<td>0,903</td>
<td>0,351</td>
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<td>A/C Type 6</td>
<td>0,516</td>
<td>0,122</td>
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</table>
• Predictive analysis allows the assessment of the impact of mitigation actions *BEFORE* implementing them.

• Impact of mitigation actions to *OTHER* incidents automatically considered (e.g. runway overrun vs. hard landing vs. tail strike).
Identifying the Unknown

Correlation Coefficient

Only captures **CONSTANT** dependency between two parameters

Copula

Capable of capturing **VARIABLE (nonlinear)** dependencies between more than two parameters
Future Work

1. Comparison between planned and actual performance
   - Takeoff planning
   - Landing distances
   - Fuel consumption
   - …

Mismatch can be expressed to quantify growth factors

2. Exploitation and correlation of further data sources:
   - ATM data
   - Weather data
   - Training data
   - Maintenance records
   - …
Predictive Analysis enables airlines:

To QUANTIFY airline-specific incident and accident probabilities BEFORE things go wrong.

To IDENTIFY and QUANTIFY HIDDEN and UNKNOWN contributing factors.

To QUANTIFY the main drivers behind incidents.

To QUANTIFY the effectiveness potential mitigation actions BEFORE implementing them.
Thank you!

Professor

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