A framework for risk management in aviation safety at state level

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with Cesar Alfaro and Javier Gómez and staff from AESA

COST ESR on Expert Judgement
ICMAT, April 2015
• Aviation Safety
• Framework for Risk Management in Aviation Safety at State Level
  – Slide deployment
  – Fuel for holding
• Expert judgement issues
• Discussion and challenges
Safety vs Security
A FRAMEWORK FOR RISK MANAGEMENT IN AVIATION
SAFETY AT STATE LEVEL (WITH AESA)

Safety is Critical in Civil Aviation
Safety is Critical in Civil Aviation

- Increasing complexity of the global air transportation system;
- Interrelated and complex nature of aviation activities;
- Traffic growth and;
- Increasing competition forcing cost reduction (even more under recession)...

We need to assure the safe operation of aircrafts through tools and methodologies supporting the continuous evolution of a proactive strategy improving safety performance

However... relatively simple tools for safety risk analysis for commercial aviation operations
<table>
<thead>
<tr>
<th>RISK MATRIX</th>
<th>Without Safety Effect</th>
<th>Significant Incident</th>
<th>Major Incident</th>
<th>Serious Incident</th>
<th>Accident</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely Unlikely</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Extremely Remote</td>
<td></td>
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<tr>
<td>Remote</td>
<td></td>
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<td></td>
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<tr>
<td>Reasonably Possible</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Frequent</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

ARMS, Bowtie, IRP,...
STATE SAFETY PROGRAMME?

- ICAO: “An integrated set of regulations and activities established by a State aimed at managing civil aviation safety”
- Support strategic decision-making in adopting better decisions when allocating scare resources to higher safety risk areas
- To implement preventive approach for safety oversight and to manage safety at a State level, States must develop a State Safety Program (SSP)
SPANISH AVIATION INDUSTRY

- Aircraft Design and Production: 14
- Airlines: 88
- Aerial Work Companies: 219
- Aircraft Maintenance Org.: >150
- Training Organizations: 117
- Aircraft (total): 6,400
- Licensed personnel: >40,000
- 232 airfields (47 airports)
- 62 ATM dependencies
- 340 Air Navigation Aids
MODELLING APPROACH

- Incident forecasting
- Incident consequence assessment and forecasting
- Risk mapping
- Deciding on interventions
- Detailed analysis of chosen incidents
STATE SAFETY PROGRAMME ACTIVITIES

Mandatory Occurrence Reporting System (SNS & CEANITA)

- SAFETY ISSUES IDENTIFICATION
- TREND DETECTION
- RISK ANALYSIS
- WEEKLY ASSESSMENT
- OTHER INPUTS

ASSESSMENT CRITERIA
- Dashboard
- Moving Average

RISK CLASSIFICATION SCHEMES

YEAR REPORTS
Top Priorities
1
2
3
4
5
OCURRENCE GROUPING

- ECCAIRS Taxonomy too broad
- An extra classification exercise is needed for data managing and exploitation

### ECCAIRS Taxonomy

#### INCIDENT FORECASTING: SAFETY RISK AREAS/ISSUES

- OCCURRENCE CLASSIFICATION
  - AIRPORT RELATED
    - GROUND HANDLING
    - AERODROME FACILITIES
    - GROUND COLLISION
  - ABRUPT MANOEUVRE
  - ABNORMAL RUNWAY CONTACT
  - RUNWAY EXCURSION
  - AIR NAVIGATION SERVICES
    - ATM/CNS
    - LOSS OF SEPARATION / MID AIR COL
    - RUNWAY INCURSION AC/VEHICLE
  - AIRWORTHINESS (TECHNICAL)
    - FIRE / SMOKE
    - SYSTEM FAILURE
    - POWERPLANT FAILURE
  - SECURITY & PREVENTION
    - SECURITY
    - MEDICAL EMERGENCY
  - EXTERNAL FACTORS
    - WINDSHEAR / THUNDERSTORM
    - TURBULENCE
    - ICING
  - UNCLASSIFIED
    - OTHER
    - UNDETERMINED

#### GROUP CATEGORY EVENT TYPE

<table>
<thead>
<tr>
<th>GROUP</th>
<th>CATEGORY</th>
<th>EVENT TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIRPORT RELATED</td>
<td>GROUND HANDLING</td>
<td>Damage by Ground vehicle, Ground Handling/Parking/Pushback procedures</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flight Dispatch/ Load Sheet/ Refueling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dangerous Goods</td>
</tr>
<tr>
<td></td>
<td>AERODROME FACILITIES</td>
<td>Design / Illumination, Aerodrome Maintenance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Runway Obstacles/FOD, Aerodrome Services, Powered Aircraft</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non Powered Aircraft, Non Powered Aircraft</td>
</tr>
<tr>
<td></td>
<td>COLLISION ON GROUND</td>
<td>Runway Incursion-Animal</td>
</tr>
<tr>
<td></td>
<td>ANIMAL RUNWAY INCURSION</td>
<td>Runway Incursion-Animal</td>
</tr>
<tr>
<td></td>
<td>RUNWAY INCURSION AC/VEHICLE</td>
<td>Runway Incursion-Animal</td>
</tr>
<tr>
<td></td>
<td>OTHER OCCURRENCES ATM/CNS</td>
<td>Deviation ATC Procedures (Pilot), Deviation AIP Procedures (Pilot)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CNS Failure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AIS Failure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Air Space Infringment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ATM Services Failure (Control)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TCAS Alert/Resolution</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loss of Separation in Flight</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Runway Incursion</td>
</tr>
</tbody>
</table>

#### SAFETY RISK AREAS

- INCIDENT FORECASTING: SAFETY RISK AREAS/ISSUES
INCIDENT FORECASTING

- (Non-homogeneous) Poisson processes
- Exploratory data analysis
  - Base rate (operations, cycles, usage)
  - Effects (Basic, seasonal, stress, geographical)
- Expert prior elicitation
- Forecasting incidents
  - Annual forecast for risk assessment
  - Monthly forecast monitoring for tracking incidents, alarm setting ('quality control')
INCIDENT RATES. EXPLORATORY ANALYSIS.

(a) Efecto Estres
(b) Efecto Estacional
(c) Efecto Estacional (Autocorrelacion)
(d) Efecto Dinámico
(e) Efecto Geográfico
(f) Efecto Geográfico (Dendograma)

These two components explain 95.33% of the point vari
### INCIDENT RATES. EXPLORATORY ANALYSIS.

**Is the type of incident standard?**

<table>
<thead>
<tr>
<th>GROUP</th>
<th>OCCURRENCE CATEGORY</th>
<th>OCCURRENCE TYPE</th>
<th>GEOGRAPHICAL VARIATION</th>
<th>STRESS EFFECT</th>
<th>SEASONAL VARIATIONS</th>
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</thead>
<tbody>
<tr>
<td>AIRPORT ENVIRONMENT</td>
<td>Handling</td>
<td>Vehicle/equipment collision with A/C</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Handling procedures</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
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<td></td>
<td></td>
<td>Flight dispatch</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dangerous goods</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inappropriate vehicle movements</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td></td>
<td>INFRASTRUCTURE</td>
<td>Design, beacon and other systems</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Airport maintenance</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
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<tr>
<td></td>
<td></td>
<td>FOD</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Airport services</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
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<tr>
<td></td>
<td>GROUND COLLISION</td>
<td>Propelled A/C</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No propelled A/C</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
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<td></td>
<td></td>
<td>Ground collision loss of separation</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
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<tr>
<td></td>
<td>ANIMAL INCURSION</td>
<td>In runway</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In ramp/twy</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td></td>
<td>MANIOPRA BRUSCA</td>
<td>Maniopra Brusca</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>
INCIDENT FORECASTING: BASIC MODEL

\[ \lambda \sim \text{Gamma}(a, p) \]

\[ X_k | \lambda, n_k \sim \text{Po}(\lambda n_k) \]

<table>
<thead>
<tr>
<th>ID</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>9</td>
<td>110</td>
<td>286</td>
</tr>
<tr>
<td>0.15</td>
<td>2.31</td>
<td>4.42</td>
<td>6.56</td>
</tr>
<tr>
<td>No. Inc</td>
<td>101</td>
<td>176</td>
<td>140</td>
</tr>
<tr>
<td>No. Oper</td>
<td>2.16</td>
<td>2.11</td>
<td>2.14</td>
</tr>
<tr>
<td>Pred. Inc.</td>
<td>130</td>
<td>100.5</td>
<td>136.4</td>
</tr>
<tr>
<td>Pred. Std.</td>
<td>41</td>
<td>17</td>
<td>8.4</td>
</tr>
</tbody>
</table>
INCIDENT FORECASTING: SEASONAL, STRESS, RELATED INCIDENTS, DYNAMIC

For type k incident

\[
x_i | \lambda_i, n_i \sim Po(\lambda_i n_i)
\]

\[
u_i = \log \lambda_i
\]

\[
\begin{cases}
  u_i = F_i \theta_i + v_i, v_i \sim N(0, V_i) \\
  \theta_i = G_i \theta_{i-1} + w_i, w_i \sim N(0, W_i) \\
  \theta_0 \sim N(\mu_0, W_0) \\
  m_i = H_i m_i + z_i, z_i \sim N(0, \Sigma_i) \\
  m_i = J_i m_{i-1} + \xi_i, \xi_i \sim N(0, S_i) \\
  m_0 \sim N(\eta_0, S_0)
\end{cases}
\]

New forecasting algorithms for new models defined

Geographical effect. Clustering, Hierarchical model
FORECASTING INCIDENT CONSEQUENCES

Model

\[ \lambda \sim \text{Gamma}(a, p) \]

\[ p_k \sim \text{Dir}(\alpha_{k1}, \ldots, \alpha_{k5}) \]

\[ X_k | \lambda, n_k \sim \text{Po}(\lambda n_k) \]

\[ m_k | p_k, X_k \sim \mathcal{M}(X_k, p_k) \]
THE PROBLEM OF UNDERREPORTING

Model

Diagram:

- $n$
- $\lambda$
- $p$
- $x$
- $s$
- $\theta$
- $z$
FORECASTING INCIDENT CONSEQUENCES

\[ t_d = p_0 I_0 + p_1 F_{d_1} + p_2 F_{d_2} \]

\[ F_{d_1} \sim \text{Wei}(\theta = 0, \alpha_1, \beta_1), \]

\[ p_0 + p_1 + p_2 = 1 \]

\[ p_0, p_1, p_2 \geq 0 \]

\[ F_{d_2} \sim p \cdot \text{Wei}(\theta = 0, \alpha_2, \beta_2) + (1 - p) \cdot \text{Wei}(\theta, \alpha_3, \beta_3) \]

\[ u(v) = -\exp(kv) \]

\[ v(n_{vm}, n_h, t_d, c_c, n_{rm}, d_{img}) = -c_{vm} n_{vm} - \sum_{i=1}^{5} c_i n_i - c_d t_d - c_c - (c_{rm} n_{rm}^1 + c_{rm} n_{rm}^2) - c_{img} d_{img} \]
FORECASTING INCIDENT CONSEQUENCES

- Expected costs

- Expected number of incidents

(FOR A LARGE NUMBER OF YEARS)

GENERATE RATE
GENERATE TYPE PROBABILITIES
INPUT NUMBER OF OPERATIONS
GENERATE N(O.INCIDENTS)
FOR I=1 TO N
    GENERATE TYPE
    GENERATE COST
RISK MAPPING

- Mapping (forecasted) incident numbers vs (forecasted) incident costs (expected, boxplots)

<table>
<thead>
<tr>
<th>Less but more expensive</th>
<th>More and more expensive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less and less expensive</td>
<td>More but less expensive</td>
</tr>
</tbody>
</table>
RISK MAPPING

Annual comparison
DECIDING ON INTERVENTIONS
DECIDING ON INTERVENTIONS

(FOR A LARGE NUMBER OF YEARS)

\[
\text{COST} = -X(=\text{SUM } X_i) \\
\text{INPUT N(UMBER OF OPERATIONS)} \\
\text{FOR EACH TYPE OF INCIDENT} \\
\text{GENERATE RATE} \\
\text{GENERATE TYPE PROBS.} \\
\text{GENERATE N(0. INCIDENTS)} \\
\text{FOR } i=1 \text{ TO } N \\
\text{GENERATE INCIDENT} \\
\text{GENERATE TYPE} \\
\text{GENERATE COST_TYPE} \\
\text{COST} = \text{COST} + \text{COST_TYPE} \\
\text{COST} = \text{COST}/N
\]

SIMULATE FOR SEVERAL X
FIT RECOLGRESSION METAMODEL
OPTIMIZE GIVEN BUDGET
DECIDING ON INTERVENTIONS

Deterministic version

\[ x = (x_1, \ldots, x_l) \]

\[ \Psi(x) = \sum_j \left[ (\lambda_{xj}^j \times n) \sum_{i=1}^5 p_{xj}^{ij} E(Cost_i^j | x_j) \right] - \sum x_j \]

\[ \lambda_{xj}^j = \lambda^j \exp(-k_j x_j) \]

\[ E(Cost_i^j | x_j) = E(Cost_i^j | 0) \exp(-c_j x_j) \]

\[ p_{xj}^{ij} = p_{0}^{ij} \exp(-p_{ij} x_j), i = 2, \ldots, 5 \]

\[ p_{xj}^{1j} = 1 - \sum p_{xj}^{ij} \]

\[ \min \Psi(x) \text{ s.t. } \sum_j x_j \leq B \]
DECIDING ON INTERVENTIONS

- Pick those in the anti-Pareto frontier
- Pick some of those more costly
- Pick some of those more frequent
- Pick those that go worse
- Pick novel issues
- Relate with resource allocation
- Screened by experts
- Finally decided by politicians
‘TOP 10’

- **Airport environment:** Handling
- **Aircraft operations:** Operations at low altitude, runway excursions
- **Air navigation service:** Runway incursions, TCAS notices, airspace infringement
- **Airworthiness:** Engine system failure in general aviation
- **Emerging issues:** Bird strikes, laser disruptions
DETAILED ANALYSIS FOR SOME INCIDENTS

- Unintended slide deployment
- Fuel for holding
- (Runway excursions)
UNINTENDED SLIDE DEPLOYMENT
FUEL FOR HOLDING

- Competition forces companies to reduce costs, without jeopardising safety.
- Fuel costs more than 25% DOC
- ATFM delays at congested airports. 1250 M euros in total costs, average.
- Airline fuel policies and regulatory requirements should ensure every flight carries enough fuel for the planned route, and additional reserve to cover deviations; e.g. ATFM delays.
- When delays occur at destination, holding may be required by ATC.
- Flight crew will be able to hold depending on the remaining fuel quantity. Inability to hold will cause divert to an alternative airport. Not a simple decision, as it entails significant DOCs.
EXPERT JUDGEMENT ISSUES

- For many safety issues little relevant data
- Priors to be elicited all over the place
  - Based on observables
  - Based on quantiles
  - Aggregate through averages
- Utilities also need to be elicited
Gracias!!! Thanks!!!

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