A framework for risk management in aviation safety at state level

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COST ESR on Expert Judgement
ICMAT, April 2015

❑ Outline

- 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

- 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

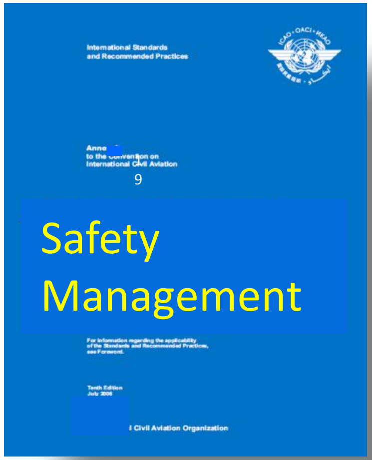
❑ SAFETY MANAGEMENT

OCCURRENCE CATEGORY / EVENT TYPE					
RISK MATRIX	Without Safety Effect	Significant Incident	Major Incident	Serious Incident	Accident
Extremely Unlikely					
Extremely Remote					
Remote					
Reasonably Possible					
Frequent					

ARMS, Bowtie, IRP,…

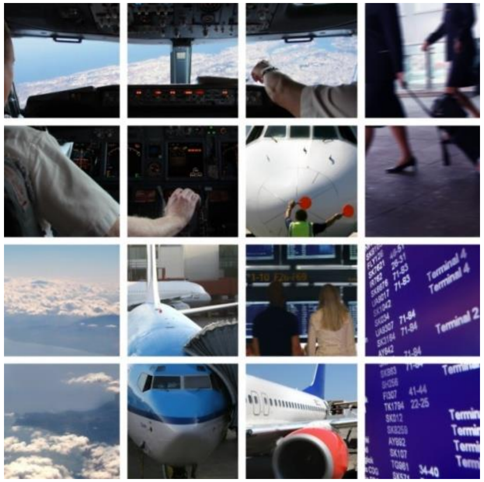
❑ STATE SAFETY PROGRAMME?

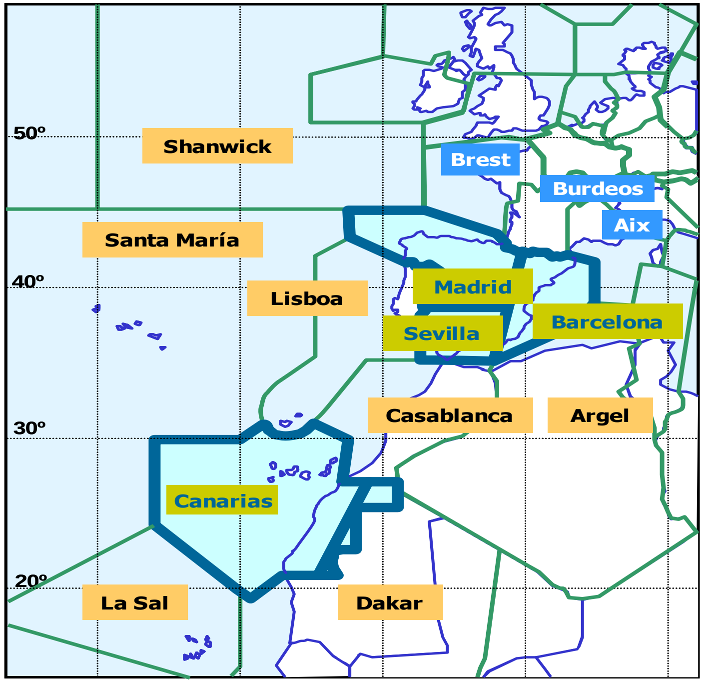
- ICAO : “An integrated set of regulations and activities established by a State aimed at managing civil aviation safety”
- Support strategic decision-making in adopting better decisions when allocating scare resources to higher safety risk areas
- To implement preventive approach for safety oversight 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



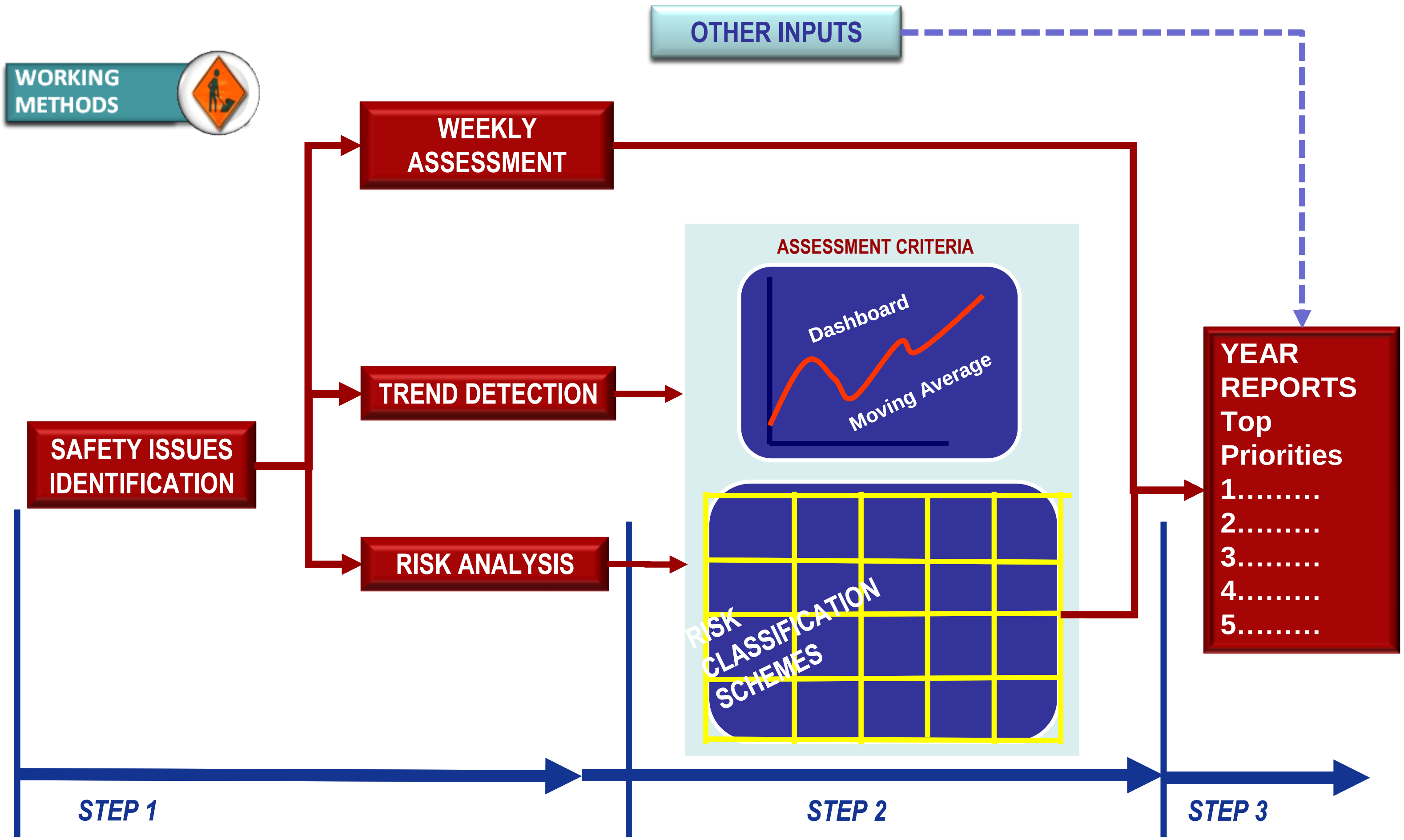


MODELLING APPROACH

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

❑ STATE SAFETY PROGRAMME ACTIVITIES

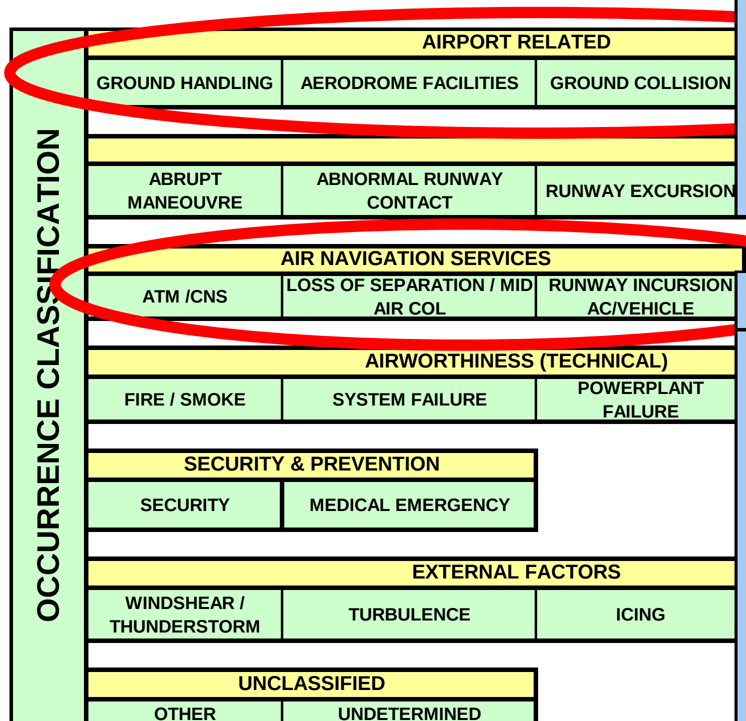
✈ **Mandatory Occurrence Reporting System (SNS & CEANITA)**



INCIDENT FORECASTING: SAFETY RISK AREAS/ISSUES

OCCURRENCE GROUPING

- ECCAIRS Taxonomy too broad
- An extra classification exercise is r… n



GROUP	CATEGORY	EVENT TYPE
AIRPORT RELATED	GROUND HANDLING	Damage by Ground vehicle
		Ground Handling/Parking/Pushback procedures
		Flight Dispatch/ Load Sheet/ Refueling
		Dangerous Goods
	AERODROME FACILITIES	Design / Ilumination
		Aerodrome Maintenance
		Runway Obstacles/FOD
		Aerodrome Services
	COLLISION ON GROUND	Powered Aircraft
		Non Powered Aircraft
	ANIMAL RUNWAY INCURSION	Runway Incursion-Animal

GROUP	CATEGORY	EVENT TYPE
AIR NAVIGATION SERVICES	OTHER OCCURRENCES ATM/CNS	Deviation ATC Procedures (Pilot)
		Deviation AIP Procedures (Pilot)
		CNS Failure
		AIS Failure
		Air Space Infrigment
		ATM Services Failure (Control)
		Other
	LOSS OF SEPARATION IN FLIGHT	TCAS Alert/Resolution
		Loss of Separation in Flight
	RUNWAY INCURSION AC/VEHICLE	Runway Incursion

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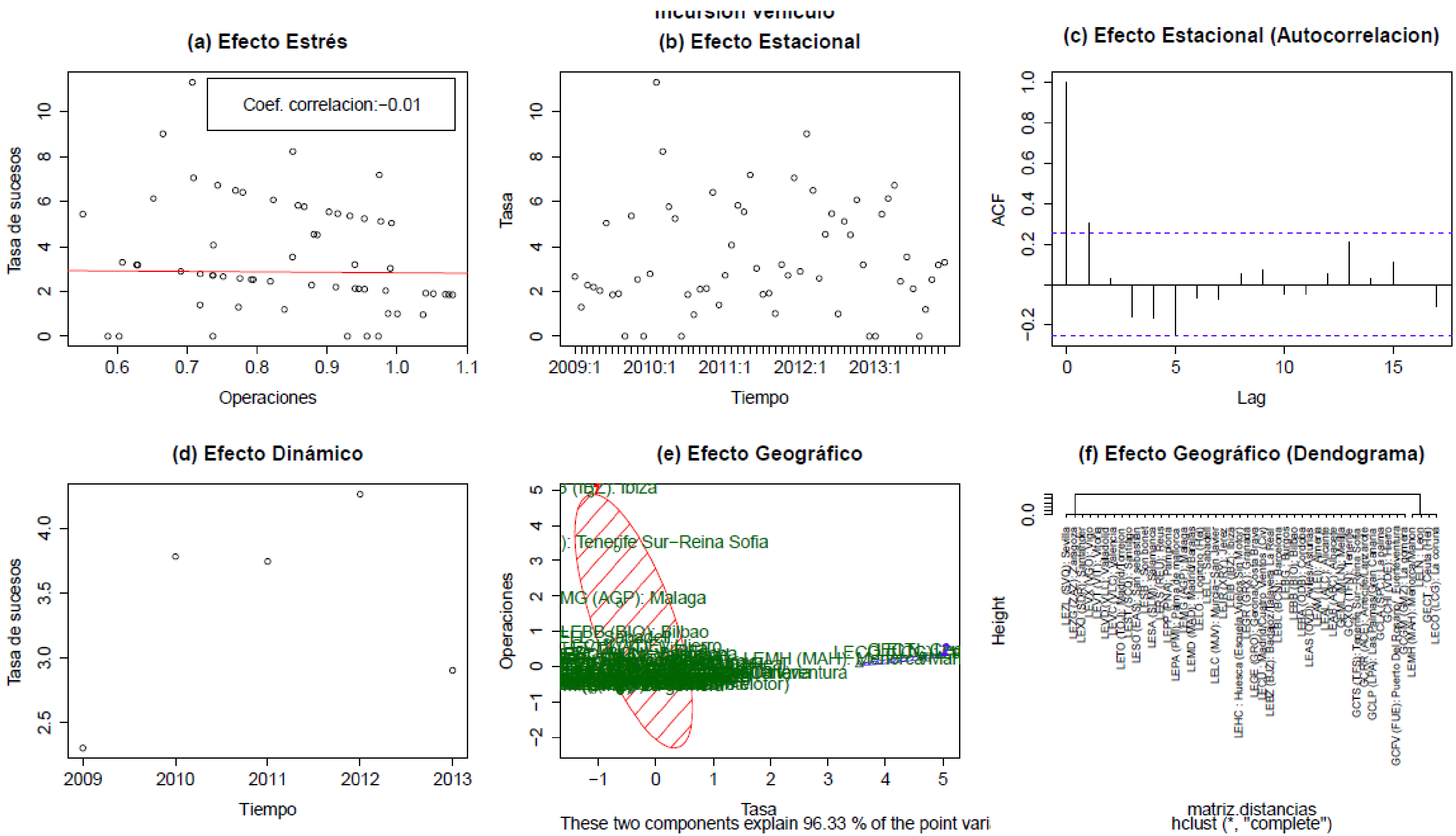
INCIDENT FORECASTING

- (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.



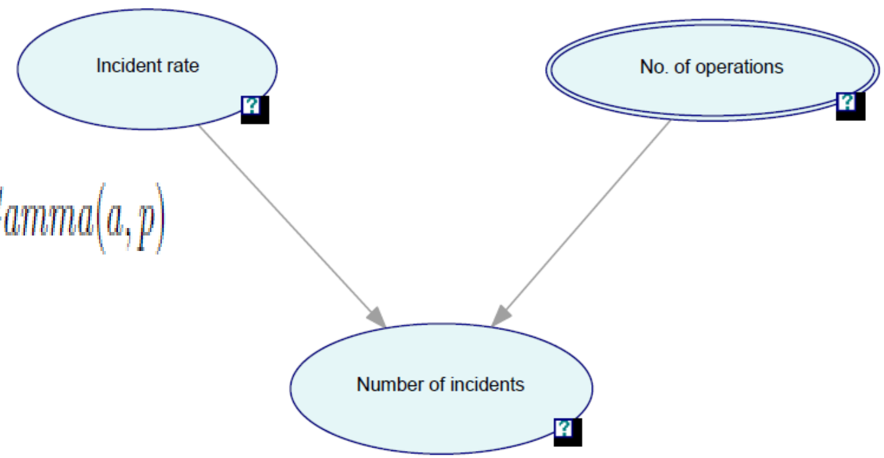
❑ INCIDENT RATES. EXPLORATORY ANALYSIS.

IS THE TYPE OF INCIDENT STANDARD?

GROUP	OCCURRENCE CATEGORY	OCCURRENCE TYPE	GEOGRAPHICAL VARIATION	STRESS EFFECT	SEASONAL VARIATIONS
AIRPORT ENVIRONMENT	HANDLING	VEHICLE/EQUIPMENT COLLISION WITH A/C	NO	NO	NO
		HANDLING PROCEDURES	NO	NO	NO
		FLIGHT DISPATCH	NO	NO	NO
		DANGEROUS GOODS	NO	NO	NO
		INAPPROPIATE VEHICLE MOVEMENTS	NO	NO	NO
		HANDLING EQUIPMENT (MAINTENANCE AND AVAILABILITY)	NO	NO	YES
	INFRAESTRUCTURE	DESIGN, BEACON AND OTHER SYSTEMS	NO	NO	NO
		AIRPORT MAINTENANCE	NO	NO	NO
		FOD	NO	NO	NO
		AIRPORT SERVICES	NO	NO	NO
	GROUND COLLISION	PROPELLED A/C	NO	NO	NO
		NO PROPELLED A/C	NO	NO	NO
		GROUND LOSS OF SEPARATION	NO	NO	NO
	ANIMAL INCURSION	IN RUNWAY	YES	NO	NO
		IN RAMP/TWY	YES	NO	NO
	MANIOBRA BRUSCA	MANIOBRA BRUSCA	NA	[illegible]	NA

INCIDENT FORECASTING: BASIC MODEL

- **ID**



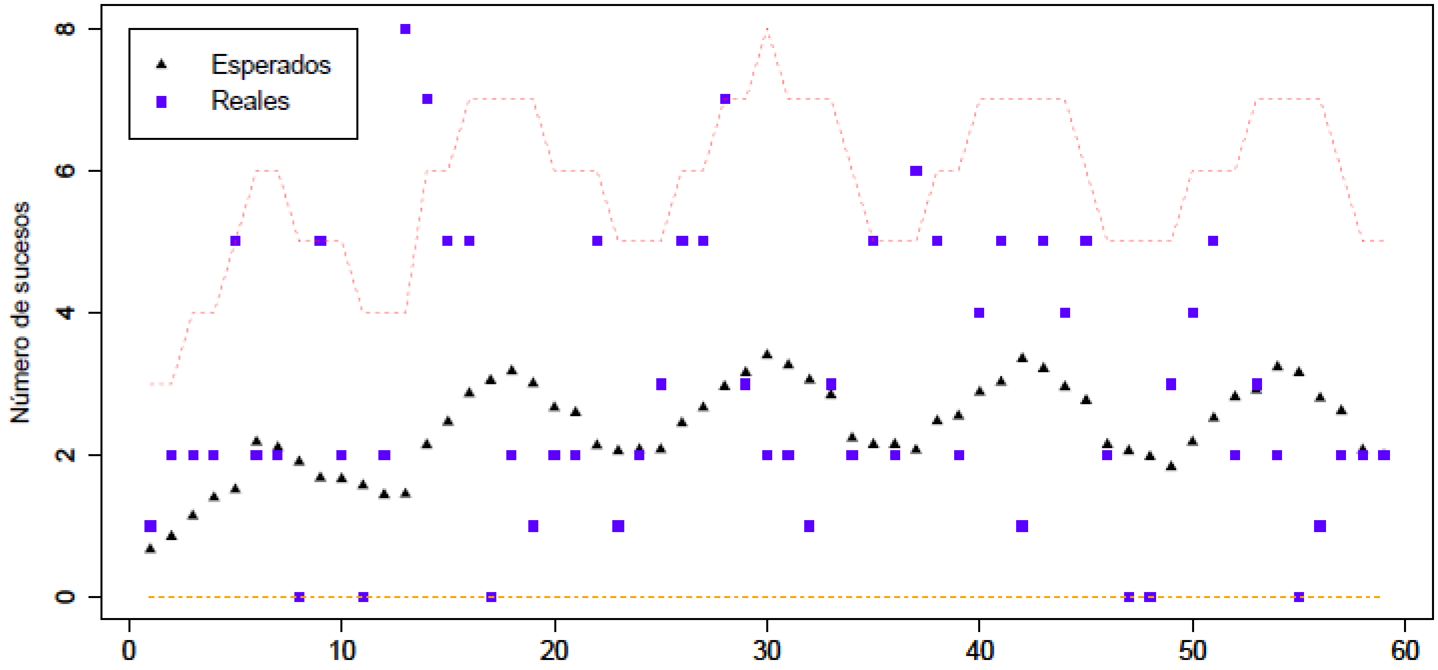
$$\lambda \sim Gamma(a,p)$$

- **Model**

$$X_k|\lambda, n_k \sim Po(\lambda n_k)$$

45
60
75

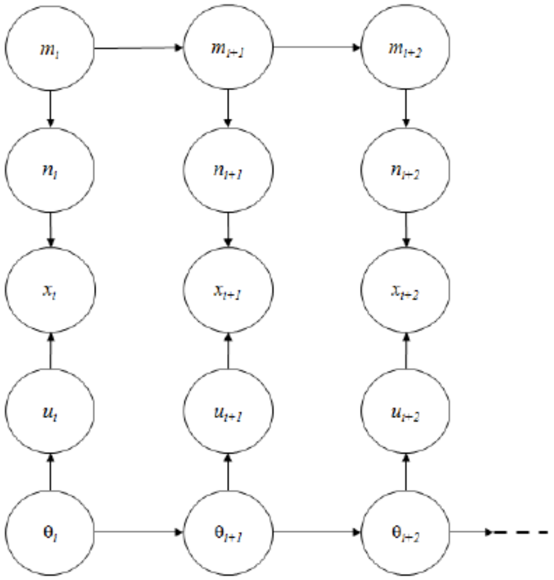
	2009	2010	2011
9	110	286	326
0.15	2.31	4.42	6.56
No. Inc	101	176	140
No. Oper	2.16	2.11	2.14
Pred. Inc.	130	100.5	136.4
Pred. Std.	41	17	8.4


Esperados
Reales
Número de sucesos
0
2
4
6
8
0
10
20
30
40
50
60

❑ INCIDENT FORECASTING: SEASONAL,STRESS, RELATED INCIDENTS, DYNAMIC

- For type k incident

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



- New forecasting algorithms for new models defined

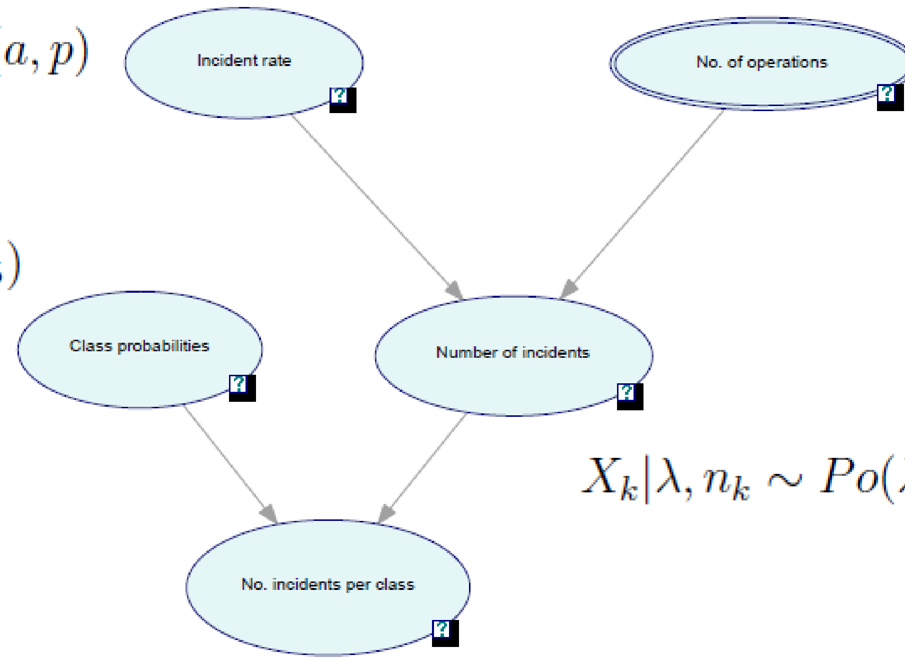
- Geographical effect. Clustering, Hierarchical model

FORECASTING INCIDENT CONSEQUENCES

Model

$$\lambda \sim Gamma(a, p)$$

$$p_k \sim \mathcal{D}ir(\alpha_{k1}, \ldots, \alpha_{k5})$$

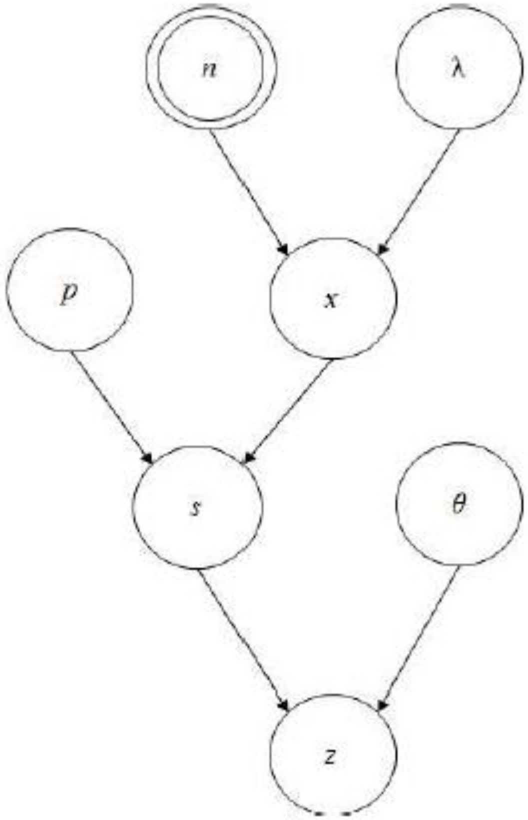


$$X_k | \lambda, n_k \sim Po(\lambda n_k)$$

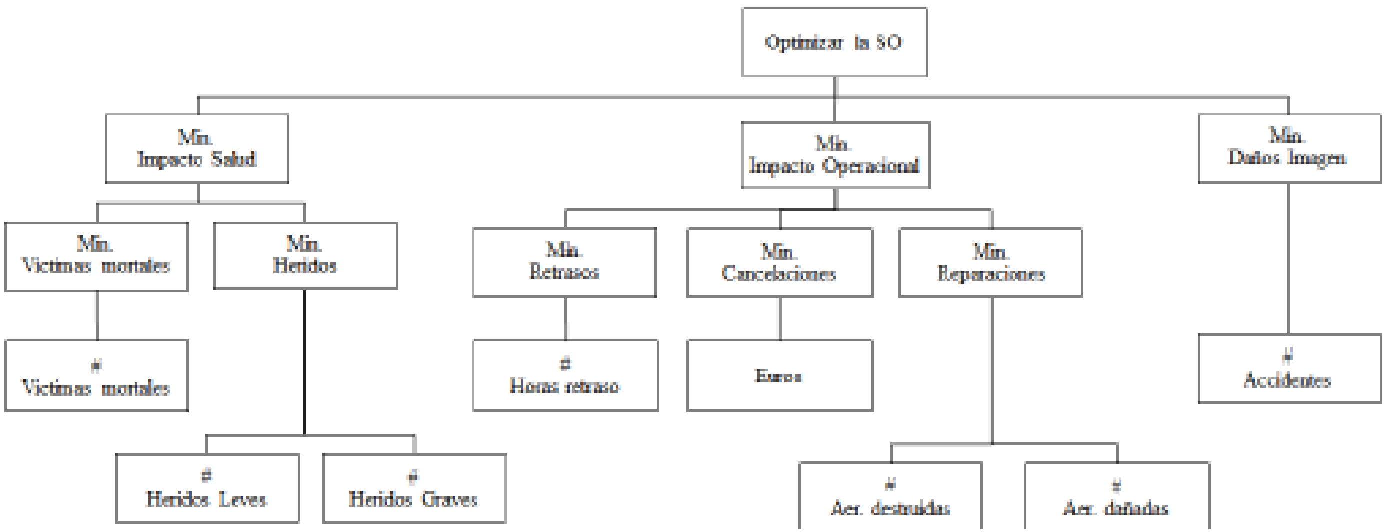
$$m_k | p_k, X_k \sim \mathcal{M}(X_k, p_k)$$

THE PROBLEM OF UNDERREPORTING

- **Model**



FORECASTING INCIDENT CONSEQUENCES



$$t_d = p_0 I_0 + p_1 F_{d_1} + p_2 F_{d_2}$$

$$F_{d_1} \sim Wei(\theta = 0, \alpha_1, \beta_1),$$

$$p_0 + p_1 + p_2 = 1$$

$$p_0, p_1, p_2 \geq 0$$

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

$$(n_{vm}, n_h, t_d, c_c, n_{rm}, d_{img}),$$

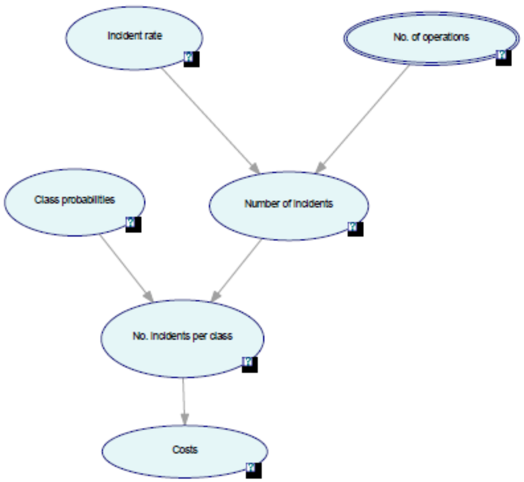
$$u(v) = -\exp(kv)$$

$$v(n_{vm}, n_h, t_d, c_c, n_{rm}, d_{img}) = -c_{vm} n_{vm} - \sum_{i=1}^{5} c_h^i n_h^i - c_d t_d - c_c - (c_{rm}^1 n_{rm}^1 + c_{rm}^2 n_{rm}^2) - c_{img} d_{img}$$

FORECASTING INCIDENT CONSEQUENCES

- **Expected costs**
- **Expected number of incidents**
- **(FOR A LARGE NUMBER OF YEARS)**

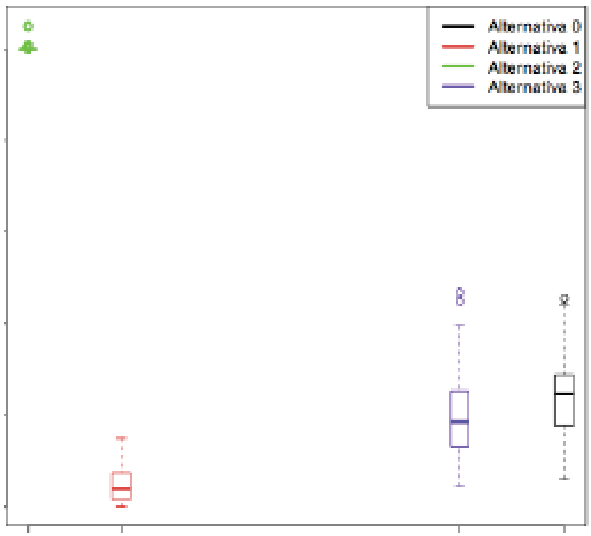
```
GENERATE RATE
GENERATE TYPE PROBABILITIES
INPUT NUMBER OF OPERATIONS
GENERATE N(O.INCIDENTS)
FOR I=1 TO N
        GENERATE TYPE
        GENERATE COST
```



❑ RISK MAPPING

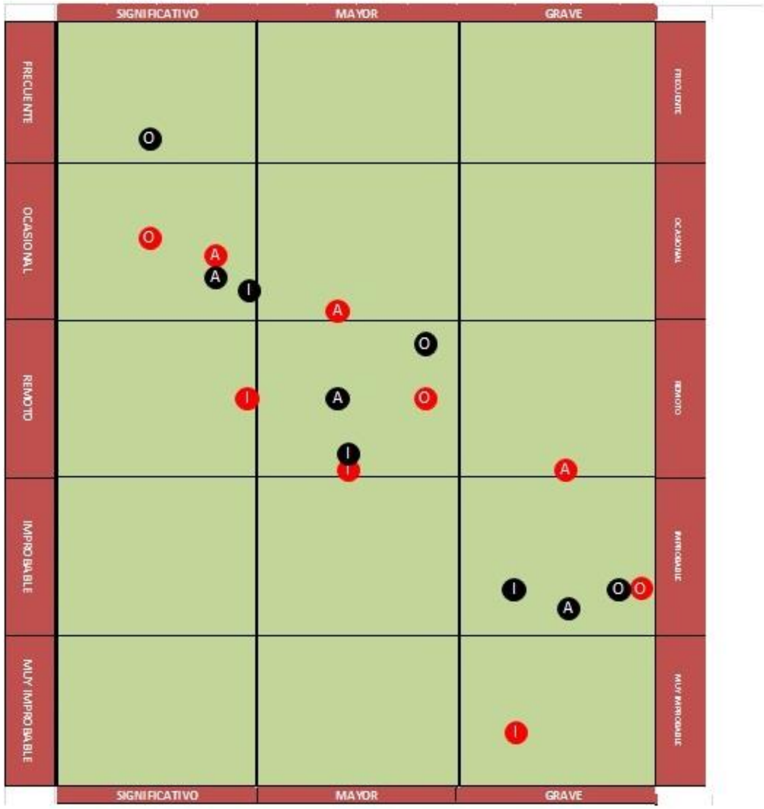
- **Mapping (forecasted) incident numbers vs (forecasted) incident costs** (expected, boxplots)

Less but more expensive	More and more expensive
Less and less expensive	More but less expensive

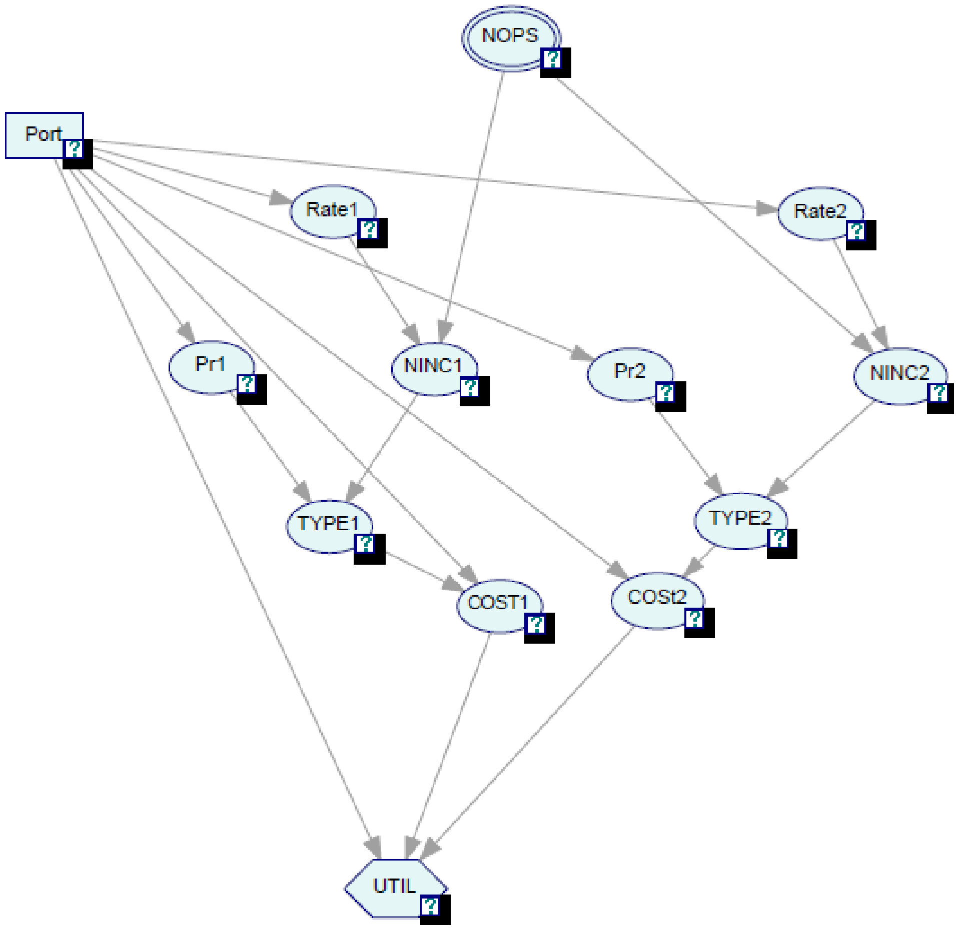


RISK MAPPING

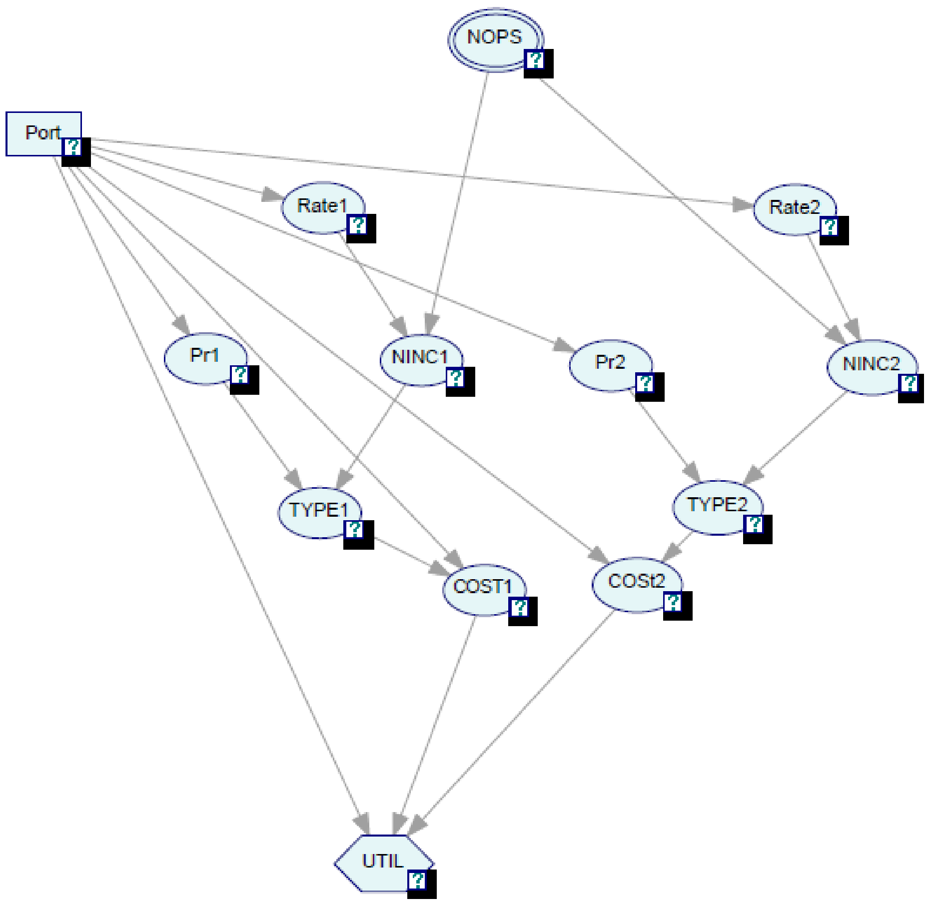
- **Annual comparison**



DECIDING ON INTERVENTIONS



DECIDING ON INTERVENTIONS



- **(FOR A LARGE NUMBER OF YEARS)**

  COST=-X(=SUM X_I)

  INPUT N(UMBER OF OPERATIONS)

  FOR EACH TYPE OF INCIDENT

  GENERATE RATE

  GENERATE TYPE PROBS.

  GENERATE N(0. INCIDENTS)

  FOR I=1 TO N

  GENERATE INCIDENT

  GENERATE TYPE

  GENERATE COST_TYPE

  COST=COST+COST_TYPE

  COST=COST/N

  SIMULATE FOR SEVERAL X

  FIT REGRESSION METAMODEL

  OPTIMIZE GIVEN BUDGET

DECIDING ON INTERVENTIONS

- **Deterministic version**

$$x = (x_1, ..., x_l)$$

$$\Psi(x) = \sum_j \left[(\lambda^j_{x_j} \times n) \sum_{i=1}^{5} p^{ij}_{x_j} E(Cost^j_i | x_j) \right] - \sum x_j$$

$$\lambda^j_{x_j} = \lambda^j \exp(-k_j x_j)$$

$$E(Cost^j_i | x_j) = E(Cost^j_i | 0) \exp(-c_j x_j)$$

$$\min \Psi(x) \; s.t. \sum_j x_j \leq B$$

$$p^{ij}_{x_j} = p^{ij}_0 \exp(-p_{ij} x_j), i = 2, ..., 5$$

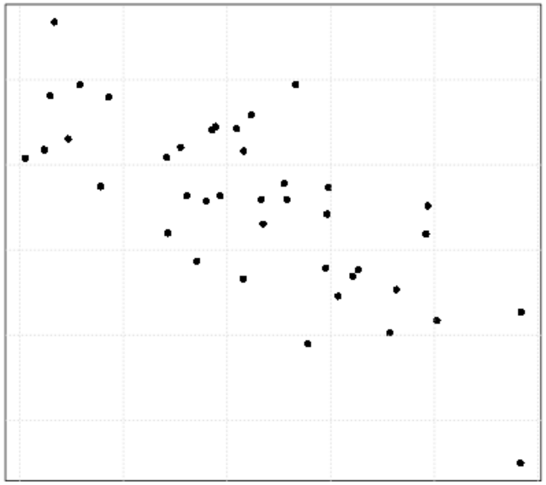
$$p^{1j}_{x_j} = 1 - \sum p^{ij}_{x_j}$$

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.

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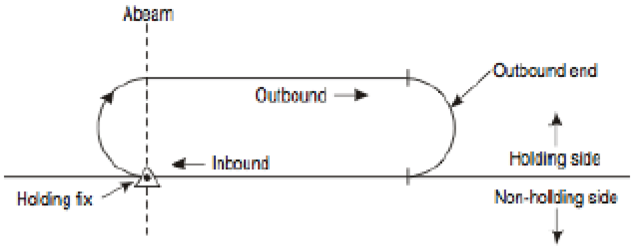

EXPERT JUDGEMENT ISSUES

- ***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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