Risk Analysis in Safety and Security in Air Transportation

David Ríos Insua
Varanasi, Jan'13

E. Sánchez, Iberia
V.Olalla, E. Herranz, P. Hdez-Coronado, J. Valero, AESA
J. Cano, URJC
D. Banks, Duke. J. Ríos, IBM

Agenda

- Safety and Security in Air Transportation
- Safety Management
  - State Safety Program
    - Unintended Slide Deployment
    - Fuel for holding
- Security Management
  - SECONOMICS
- Discussion

Safety vs Security

- Critical in Civil Aviation

- Safety. Nature, Accidents
- Security. Purposeful (terrorism,…)

- Frequently dissociated (Even for resource allocation purposes!!!)

Safety vs Security

SAFETY

- Safety is Critical in Civil Aviation

We are doing well but…

…not enough

❑ 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

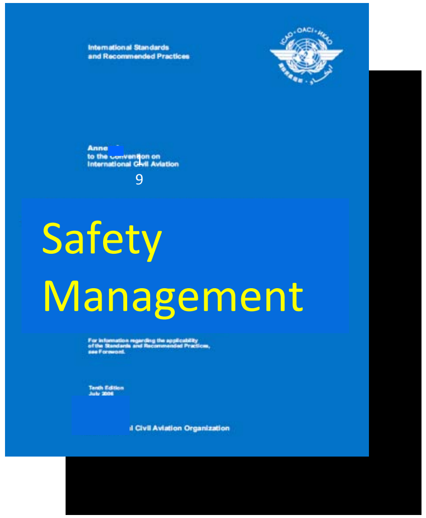
❑ SAFETY MANAGEMENT

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,...

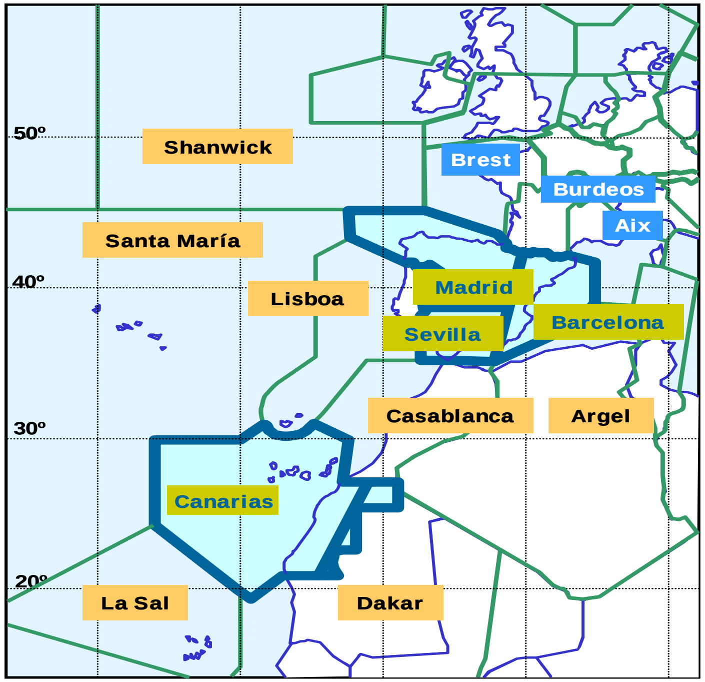
❑ STATE SAFETY PROGRAMME?

- 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



SPANISH AVIATION INDUSTRY

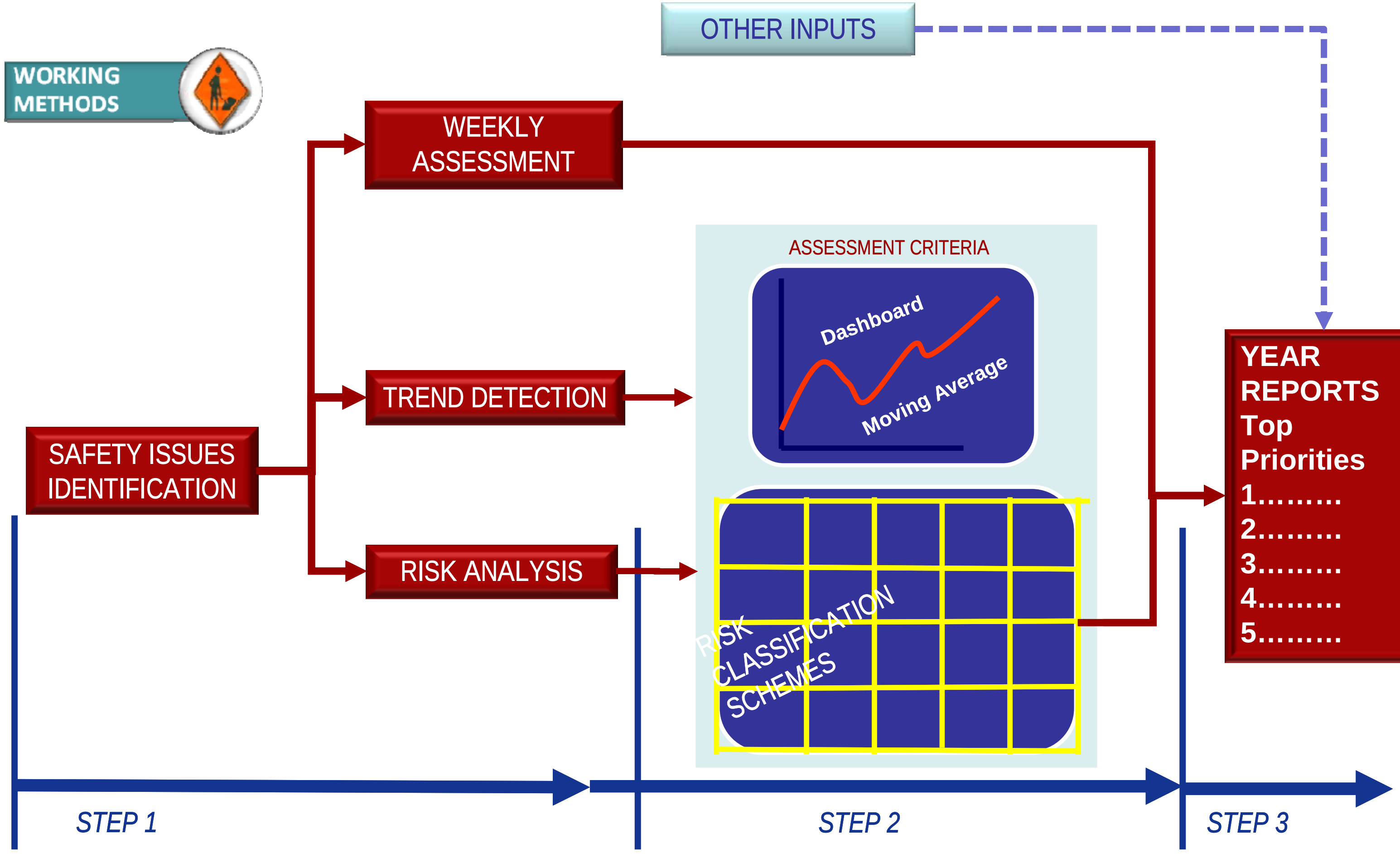
- **204 M pax in Spanish Airports in 2011**
  - **Madrid Barajas:**
    - 49,671,270 pax
    - 429,390 Movements
    - 10th largest airport in the world, 4th in Europe
  - **Barcelona:**
    - 34,398,226 pax
    - 303,054 Movements
    - 9th largest airport in Europe

PROJECT METHODOLOGY

- 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)



OCCURRENCE GROUPING

- ECCAIRS Taxonomy too broad
- An extra classification exercise is … on

OCCURRENCE CLASSIFICATION

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

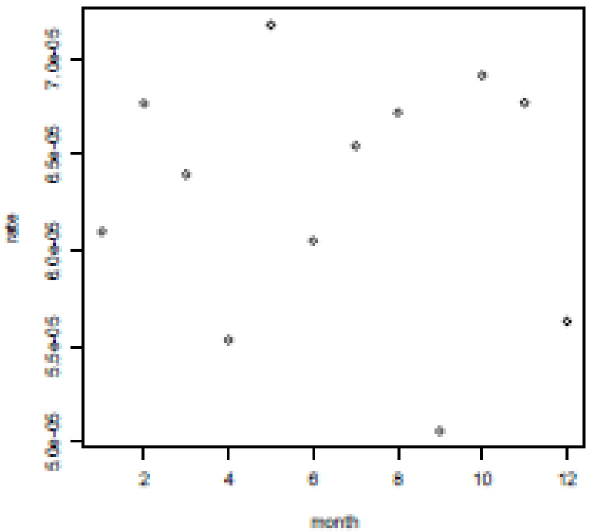
GROUP	CATEGORY	EVENT TYPE
AIR NAVIGATION SERVICES	OTHER OCCURRENCES ATM/CNS	Deviation ATC Procedures (Pilot)
		Deviation AIP Procedures (Pilot)
		CNS Failure
		AIS Failure
		Air Space Infrigment
		ATM Services Failure (Control)
		Other
	LOSS OF SEPARATION IN FLIGHT	TCAS Alert/Resolution
		Loss of Separation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

13

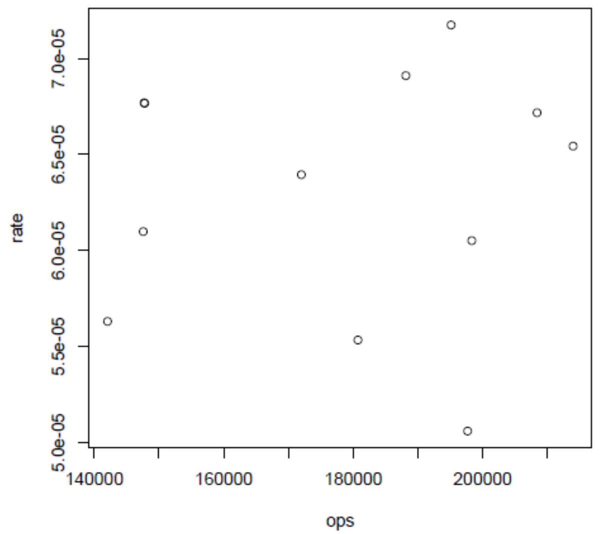
INCIDENT FORECASTING

- (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 for tracking incidents, alarm setting ('quality control')

INCIDENT RATES. EXPLORATORY ANALYSIS. RUNWAY INCURSIONS



Seasonal



Stress

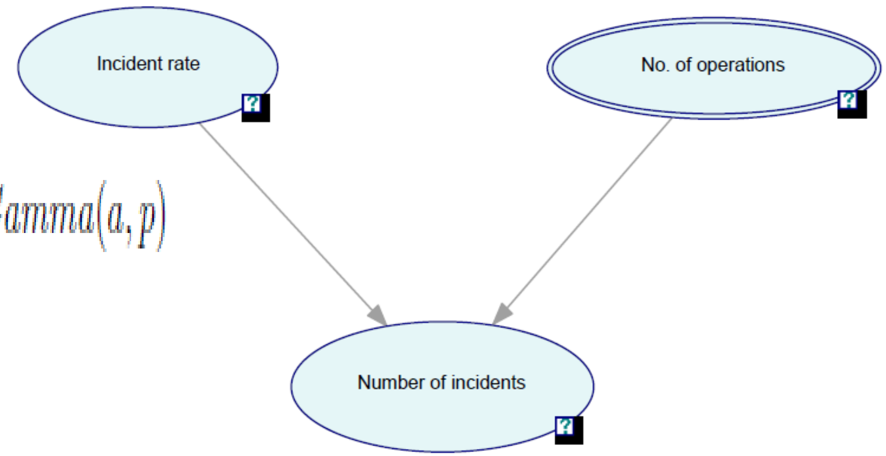
❑ INCIDENT RATES. EXPLORATORY ANALYSIS.

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
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

❑ 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

INCIDENT FORECASTING: SEASONAL,STRESS, RELATED INCIDENTS, DYNAMIC

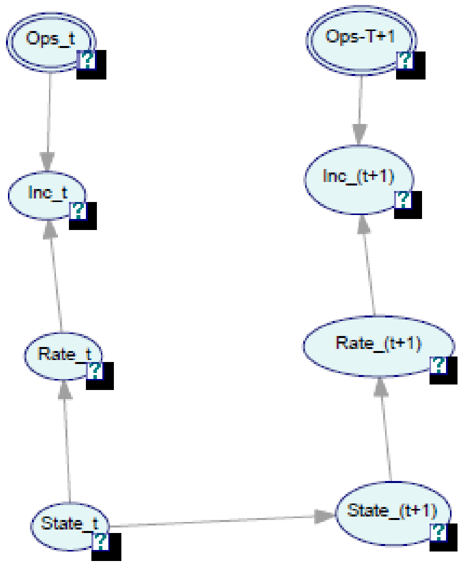
- **For type k incident**

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

$$u_k = \log(\lambda_k)$$

$$u_k = F_k\theta_k + v_k, \quad v_k \sim N(0, V)$$

$$\theta_k = G_k\theta_{k-1} + w_k, \quad w_k \sim N(0, W)$$



- **Particle filtering for update and forecasting**

- **Geographical effect. Clustering, Hierarchical model**

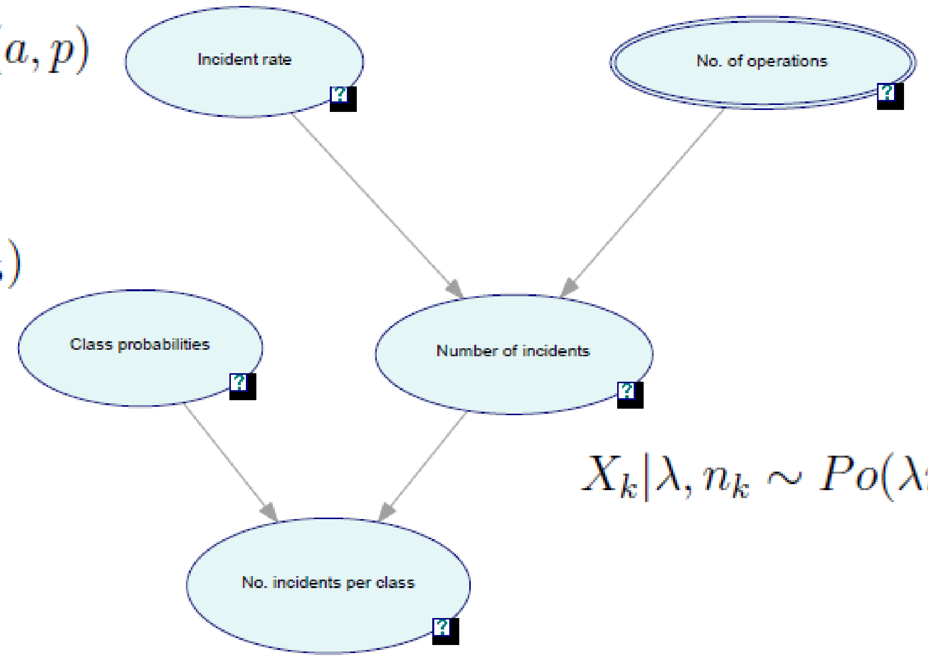
INCIDENT FORECASTING. TYPES OF INCIDENTS

MINOR	SIGNIFICANT INCIDENT	MAJOR INCIDENT	SERIOUS INCIDENT	ACCIDENT
An incident which has no safety significance. N.B. This appears to be a contradiction with the ICAO definition of an incident:	An incident involving circumstances indicating that an accident, a serious or major incident could have occurred, if the risk had not been managed within safety margins, or if another aircraft had been in the vicinity.	An incident associated with the operation of an aircraft, which safety of aircraft may have been compromised, having led to a near collision between aircraft with ground or obstacles.	An incident involving circumstances indicating that an accident nearly occurred.	An occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, in which: a) a person is fatally or seriously orb) the aircraft sustains damage or structural failure orc) the aircraft is missing or is completely inaccessible.

Predefined by ICAO and EUROCONTROL

FORECASTING INCIDENT CONSEQUENCES

Model



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

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

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

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

FORECASTING INCIDENT CONSEQUENCES

- **Initial approach**

Acc	Serious	Major	Significant	Minor
300	100	25	1	0.25

- **General initial model**

BIRD STRIKE EVENT SEVERITY	RELATED COSTS					
	Fatalities	Injuries	Delays	Compensations	Repairing	Image
ACCIDENT	100	100	100	100	100	100
SERIOUS INCIDENT	0	0	80	80	50	80
MAJOR INCIDENT	0	0	30	30	0	60
SIGNIFICANT INCIDENT	0	0	0	0	0	30
MINOR INCIDENT	0	0	0	0	0	10

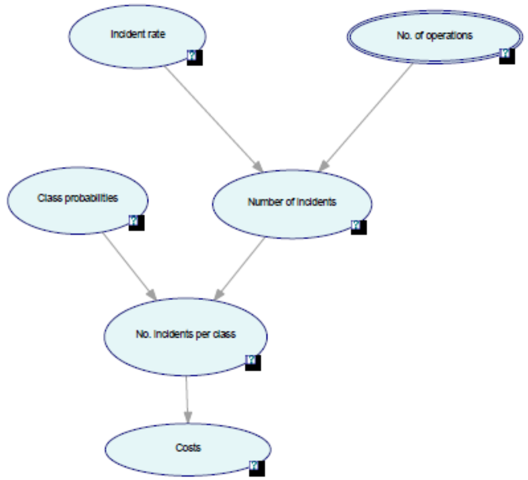
$$p_1 F_1 + p_2 F_2 + p_3 F_3 + p_4 F_4 + p_5 F_5$$

Each Fi decomposed in terms. Each term a triangular

- **Detailed analysis for interesting incidents, as available**

FORECASTING INCIDENT CONSEQUENCES

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

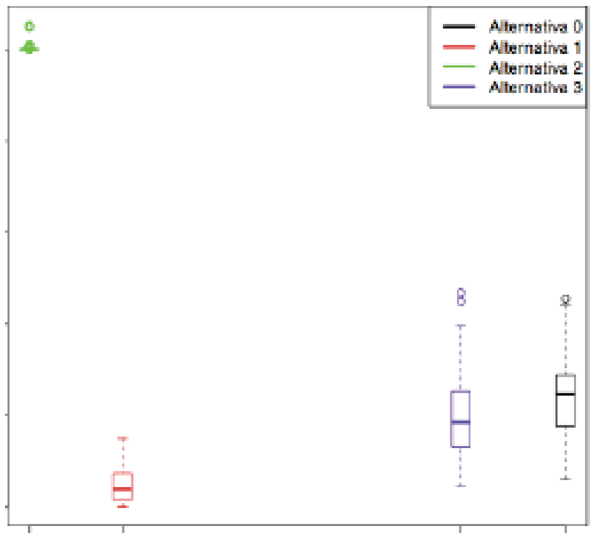


GENERATE RATE
GENERATE TYPE PROBABILITIES
INPUT NUMBER OF OPERATIONS
GENERATE N(O.INCIDENTS)
FOR I=1 TO N
        GENERATE TYPE
        GENERATE COST

RISK MAPPING

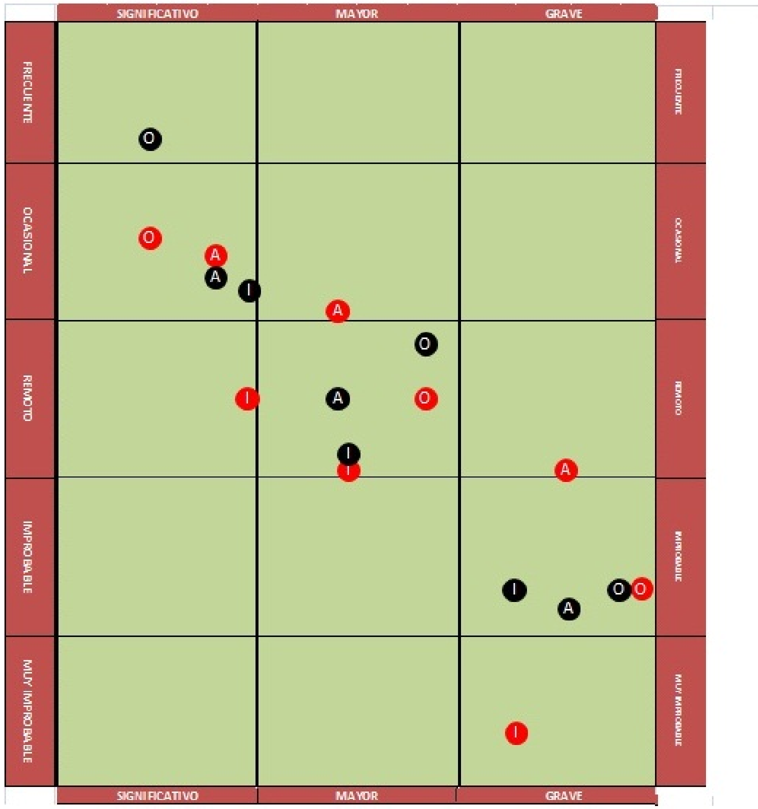
- **Mapping (forecasted) incident numbers vs (forecasted) incident costs** (expected, boxplots)

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

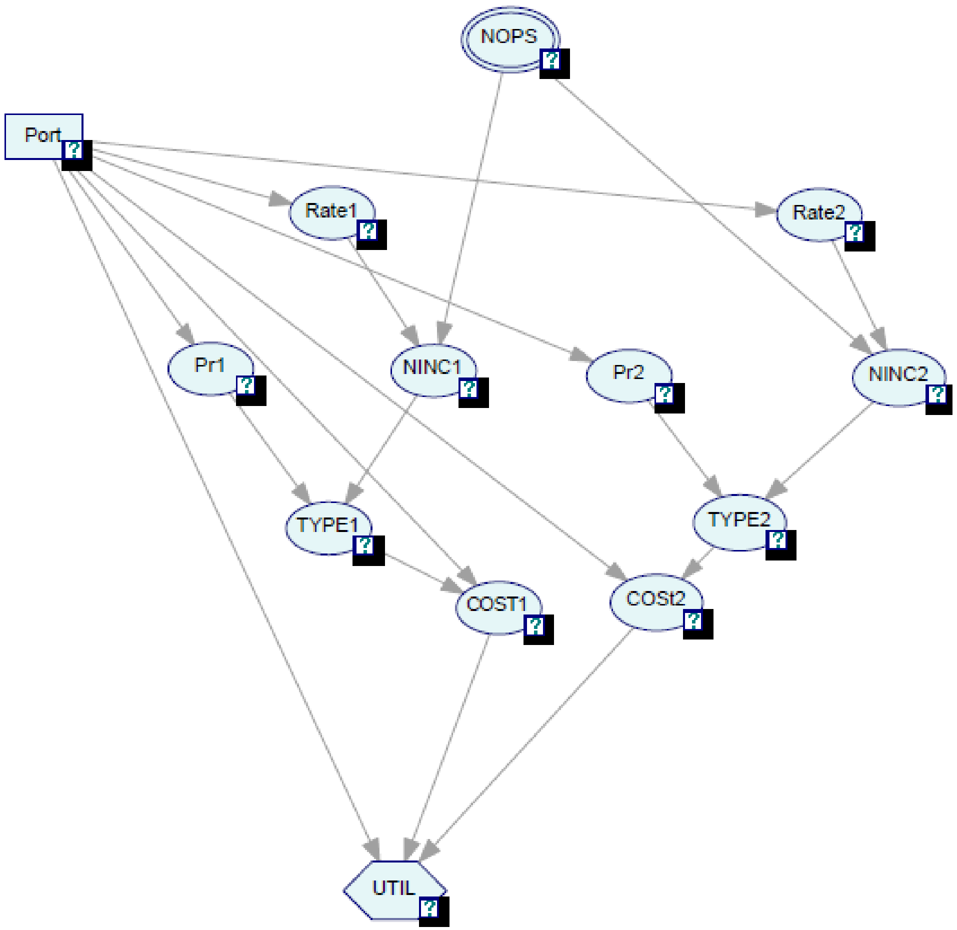


❑ RISK MAPPING

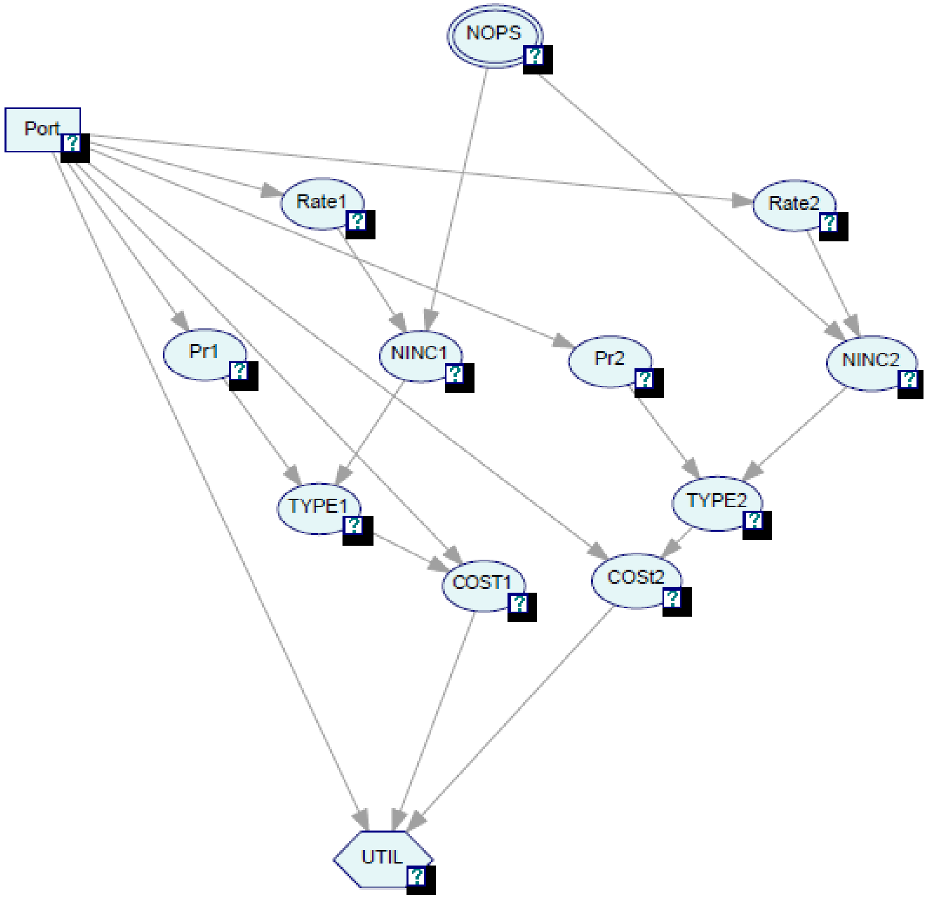
✈ Annual comparison



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**

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

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

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

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

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

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

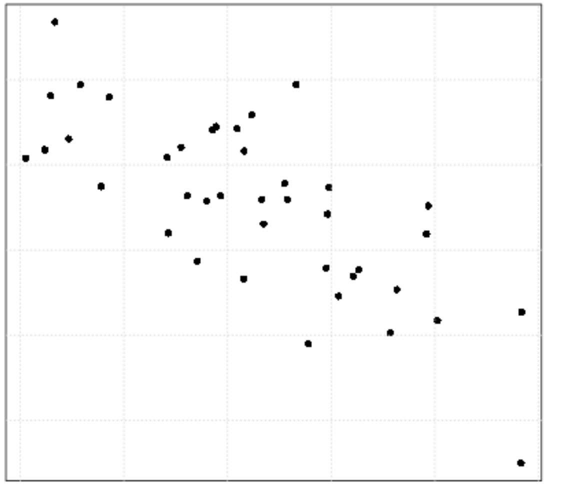
$$p^{1j}_{x_j} = 1 - \sum p^{ij}_{x_j}$$

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’ 2011

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

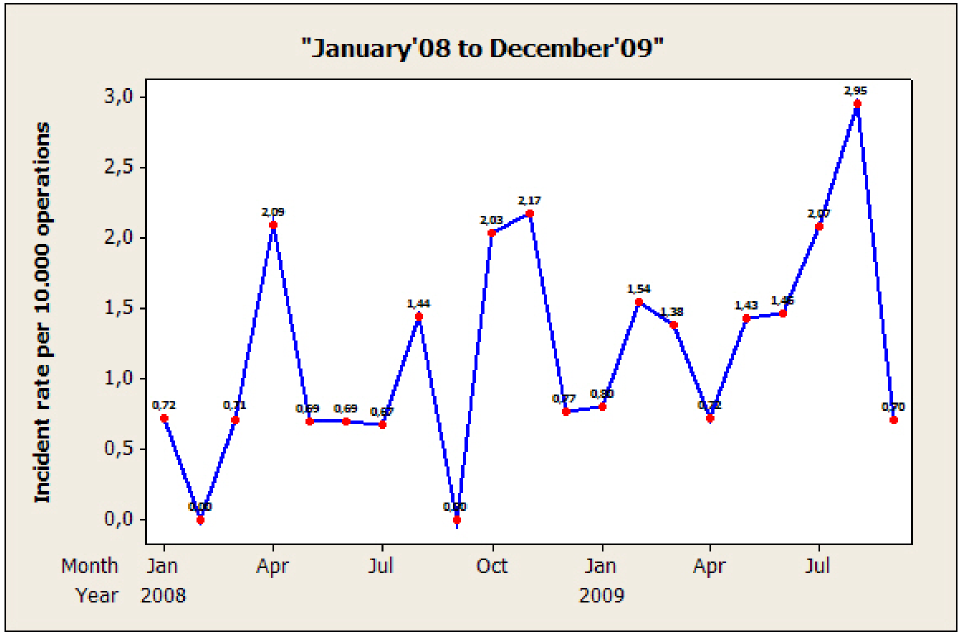
DETAILED ANALYSIS FOR SOME INCIDENTS

- ***Unintended slide deployment***
- ***Fuel for holding***
- ***Runway excursions***

UNINTENDED SLIDE DEPLOYMENT

UNINTENDED SLIDE DEPLOYMENT

- Unintended slide deployment under normal operations
- Inflatable slides to facilitate passenger evacuation in emergency situations
- (Expected) cost 20 million USD/year for the whole industry



UNINTENDED SLIDE DEPLOYMENT. DETAILED INCIDENT ANALYSIS

- **The following potentially affecting factors are identified**

Factor	Relevance	Factor levels
Aircraft type	Yes, Moderate	A > B
Airport	No	Nearly 50
Pairing day	Yes	First > Second > Third
Flight turn	Yes	First > (Second, Third)

- **We build a logistic regression model with three explanatory variables**
- **Relevant operational phase and personnel involved**

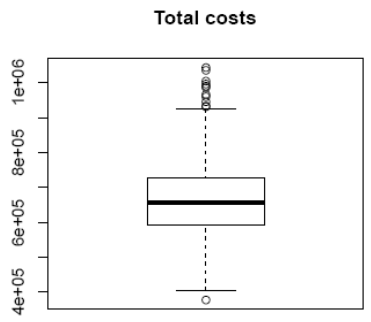
Factor	Relevance ranking
Operational phase	Arrival > Departure >> Refueling > Preflight = Stopover
Staff involved	(A, B) > (C,D,E,F,G,H,I)

- **7 errors, 9 procedure interruptions, 19 procedure non compliances (Dirichlet model)**

UNINTENDED SLIDE DEPLOYMENT. DETAILED COST ANALYSIS

Costs

- **Removal cost**
  - » Lab x Tm
  - » Tm. Expert assesses min (30), max (60), most likely (45). Adjust triangular distribution with 0.05, 0.95 quantiles at min, max . Tri (0.385,0.75,1.115)



- **Transportation cost**
- **Repair cost**
- **Ground delay associated costs**

UNINTENDED SLIDE DEPLOYMENT. DETAILED COST ANALYSIS

- **Costs in relation with delays**

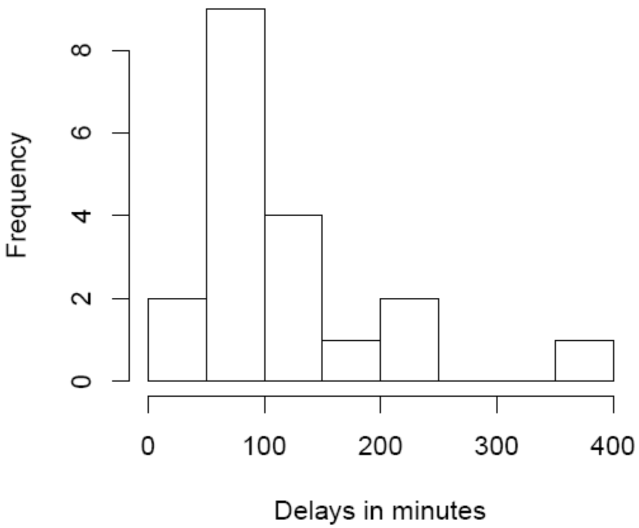
$$T_d = p_0 \ I_0 + p_1 \ F_d \qquad p_0 | data \sim Be(14, 23)$$

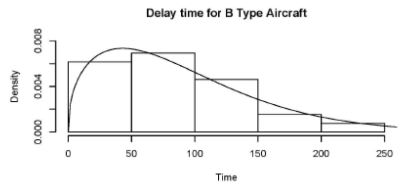
$$p_0 + p_1 = 1$$

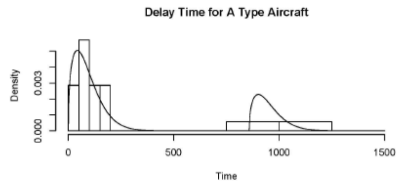
$$p_0, p_1 \geq 0$$

$$F_{d_B} \sim Wei(\theta = 0, \alpha, \beta)$$

$$F_{d_A} \sim p \ Wei(\theta = 0, \alpha, \beta) + (1 - p) \ Wei(\theta, \alpha, \beta),$$







	A Flights	B Flights
	(Min, most likely, max)	(Min, most likely, max)
Passenger Hard Costs	(0.12, 0.19, 0.24)	(0.12, 0.19, 0.24)
Passenger Soft Costs	(0.06, 0.19, 0.22)	(0.06, 0.19, 0.22)
Marginal Crew Costs	(0.00, 14.00, 39.00)	(0.00, 7.90, 16,59)
Marginal Maintenance Costs	(0.65, 0.81, 0.97)	(0.38, 0.47, 0.56)
Total Costs	(0.83, 15.19, 40.27)	(0.56, 8.75, 17.61)

UNINTENDED SLIDE DEPLOYMENT: RISK MANAGEMENT

- **Countermeasures**
  - **Change procedure (to 'eliminate' interruptions and mitigate errors, pratically no cost)**
  - **Training course to key personnel**
  - **Awareness campaign to key personnel through newsletters, etc…**
  - **Light and sound warning device at each door**
  - **Visual reminders at each door**
- **We only affect incident likelihood, but not incident severity**

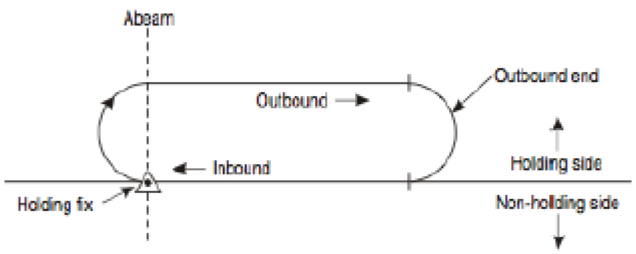
Countermeasure	1 year	5 years
Procedure revision	252902	1214935
Awareness campaign	524477	2492943
Warning devices, St. 1	1307393	1335514
Warning devices, St. 2	616058	2137866
Visual reminders, St. 1	631403	2881078
Visual reminders, St. 2	677329	3228759
None	663400	1490047

Countermeasure	1 year	5 years
Awareness campaign	123724	567739
Warning devices,St. 1	1302529	1312149
Warning devices, St. 2	352862	873480
Visual reminders, St. 1	273448	1161478
Visual reminders, St. 2	236060	1108918
None	252902	1214935

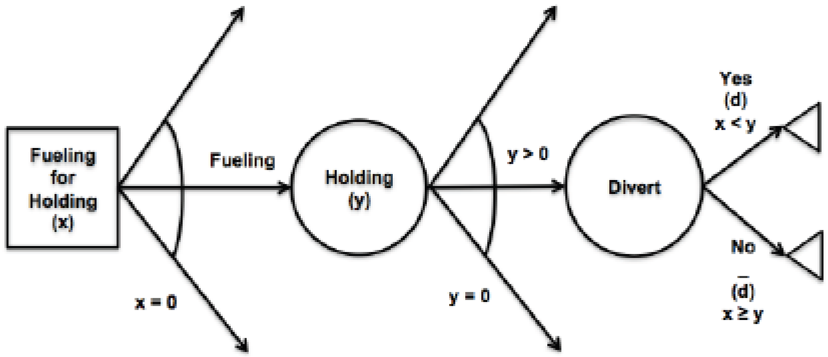
- **For a company which implemented the procedure revision from 20/year to 6/year**

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.

- 

FUEL FOR HOLDING: MODEL



Case	x	y	FCP	Delay holding costs	Diversion plus handling costs
1	$x > 0$	$y > x$	Yes	No	Yes
2	$x > 0$	$y \leq x$	Yes	Yes	No
3	$x > 0$	$y = 0$	Yes	No	No
4	$x = 0$	$y > x = 0$	No	No	Yes
5	$x = 0$	$y = 0$	No	No	No

$$\max_{x \geq 0} \psi(x) = \int \Big\{ p \cdot u(x, 0, \bar{d}) +$$

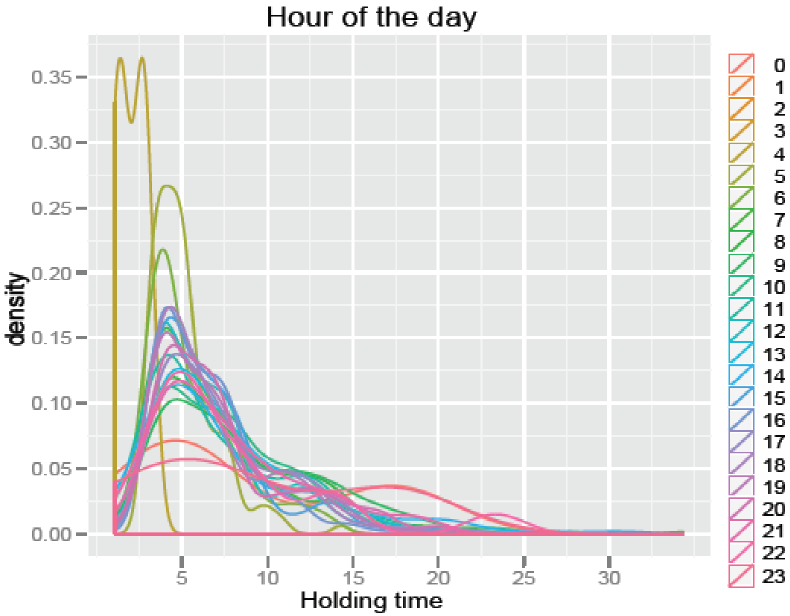
$$+ (1-p) \Big[\int_{y \leq x} f(y) u(x, y, \bar{d}) dy + \int_{y > x} f(y) u(x, y, d) dy \Big] \Big\} g(p) dp.$$

FUEL FOR HOLDING: DETAILED COSTS

- Diversion costs, $C_{Diversion}$.
  1. Proceeding from the holding point to the alternate airport (*En-Route Phase 1 Delay Cost*), C_1.
  2. Turnaround at the alternate airport (*At-Gate Phase 2 Delay Cost*), C_2. We include also *Handling costs*, $C_{Handling}$.
  3. Proceeding from the alternate airport to the original destination airport (*En-Route Phase 3 Delay Cost*), C_3.
- Delay holding costs, $C_{Holding}$.
- Fuel carriage penalty costs, C_{FCP}.

FFH: CASE

$$p|data \sim \mathcal{B}e(1+s, 1+n-s).$$



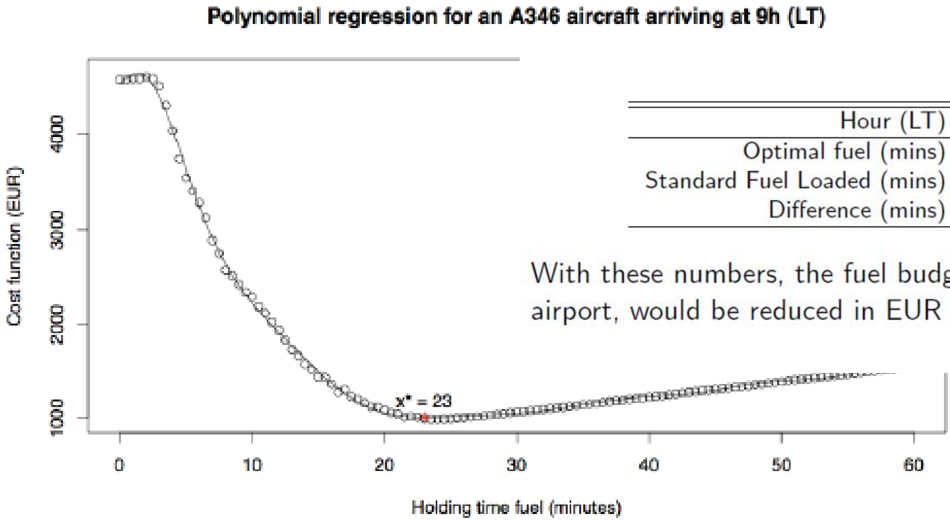
We adopt a gamma mixture model approach with four mixture components, corresponding to four full turns when holding.

$$f(y|w,\mu,\nu) = \sum_{i=1}^{4} w_i \cdot \mathcal{G}(y|\nu_i, \nu_i/\mu_i)$$

$$\begin{aligned} w &\sim \mathcal{D}(\phi) \rightsquigarrow \text{a Dirichlet distribution}, \\ \nu_i &\sim \mathcal{E}(\theta) \rightsquigarrow \text{an exponential distribution}, \; i = 1, \ldots, 4, \\ \mu_i &\sim \mathcal{IG}(\alpha, \beta) \rightsquigarrow \text{an inverted gamma distribution}, \; i = 1, \ldots, 4, \end{aligned}$$

FFH: CASE

- A flight approaches the destination airport at 09:00 LT after 9 hours and 35 mins of flight time. The aircraft was dispatched at the departing airport with 2,490 kg of fuel for holding 20 minutes at destination in case of ATFM delays.
- We set $T_{max} = 60$ min, dividing $[0, T]$ in $M = 120$ subintervals of length $l = T/M = 30$ s. We then undertake a Monte Carlo approximation at each time



Hour (LT)	9	14	17	21	23
Optimal fuel (mins)	23	25	17	19	0
Standard Fuel Loaded (mins)	20	30	20	20	0
Difference (mins)	+3	-5	-3	-1	0

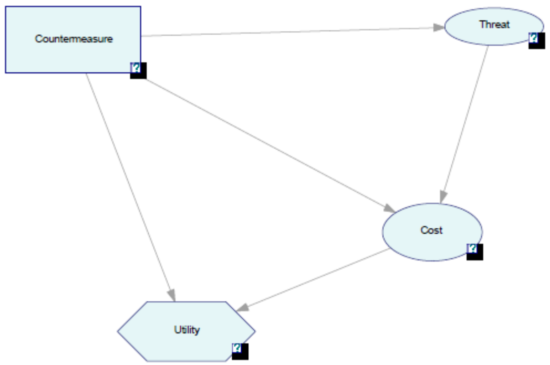
With these numbers, the fuel budget for this aircraft type, at this airport, would be reduced in EUR 12,000 per year approximately.

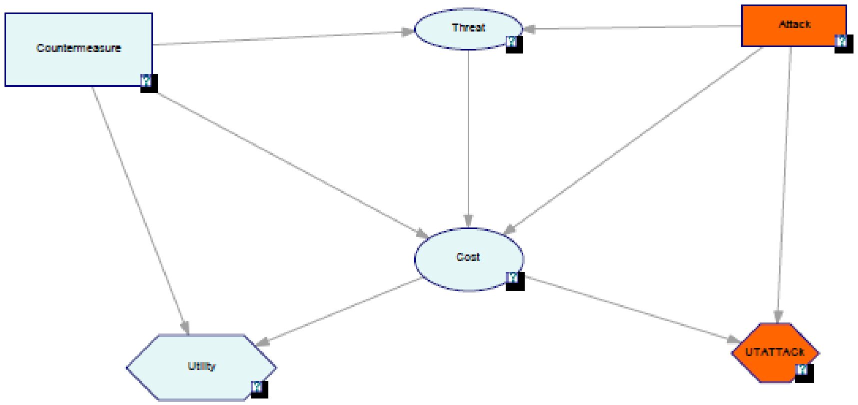
- Type of airplane
- Risk Aversion
- Image costs

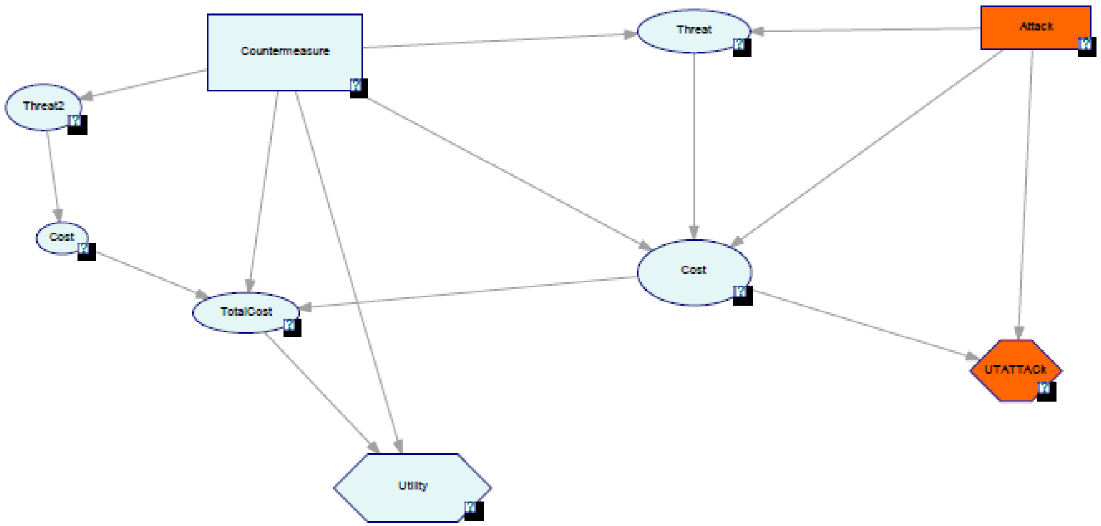
SECURITY

- EU project: SECONOMICS
- Economics of Security for critical infrastructures
  - National Grid
  - Airport
  - Metro
- Adversarial risk analysis
- ARA+RA

SECONOMICS


Countermeasure
Threat
Cost
Utility


Countermeasure
Threat
Attack
Cost
Utility
UTATTACK


Countermeasure
Threat
Attack
Threat2
Cost
TotalCost
Cost
UTATTACK
Utility

DISCUSSION: PROJECT RELEVANCE

- **To our knowledge, first time that DA used in processes related with preventive approach to safety oversight in civil aviation**

- **Aviation remains one of the most advanced means of transportation technologically wise. But the industry and regulators have implemented little modern DA methodologies**

❑ DISCUSSION: CURRENT ISSUES

- **Detailed analysis of further incidents**
- **Automating/speeding analysis**
- **Policy models. Private-public partnership. Sharing costs**
- **Safety vs security. SECONOMICS**