Supporting the design of a state aviation safety plan

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8th R Spain, Albacete
SPONSORS: AESA, MINECO, AXA

Agenda

- **Safety in Air Transportation**
- Elaborating the State Safety Program
- RIMAS: An R architecture for aviation safety risk management
- Discussion

Safety vs Security

- Critical in Civil Aviation.
  - Country
  - Company

- 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 Critical in Civil Aviation**
  - **Increasing complexity of global air transportation system;**
  - **Interrelated and complex nature of aviation activities;**
  - **Traffic growth and;**
  - **Increasing competition forcing cost reduction (even more under crisis)…**

Need assure safe operation of aircrafts through tools and methodologies supporting continuous evolution of a proactive strategy improving safety performance

However… relatively simple tools for safety risk analysis for commercial aviation operations

❑ SAFETY MANAGEMENT

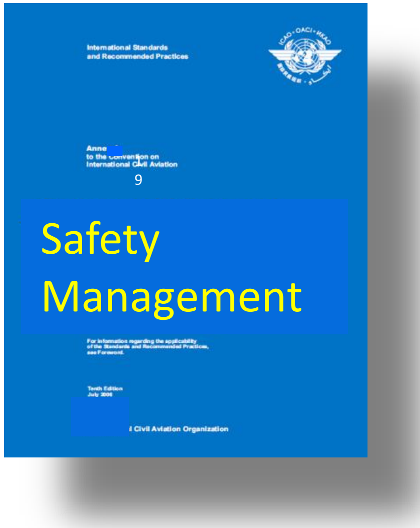
OCCURRENCE CATEGORY / EVENT TYPE					
RISK MATRIX	Without Safety Effect	Significant Incident	Major Incident	Serious Incident	Accident
Extremely Unlikely					
Extremely Remote					
Remote					
Reasonably Possible					
Frequent					

Cox (2008) criticisms

ARMS, Bowtie, IRP,…

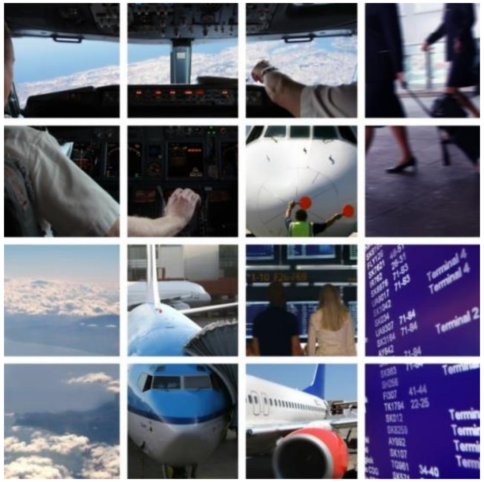
❑ STATE SAFETY PROGRAMME?

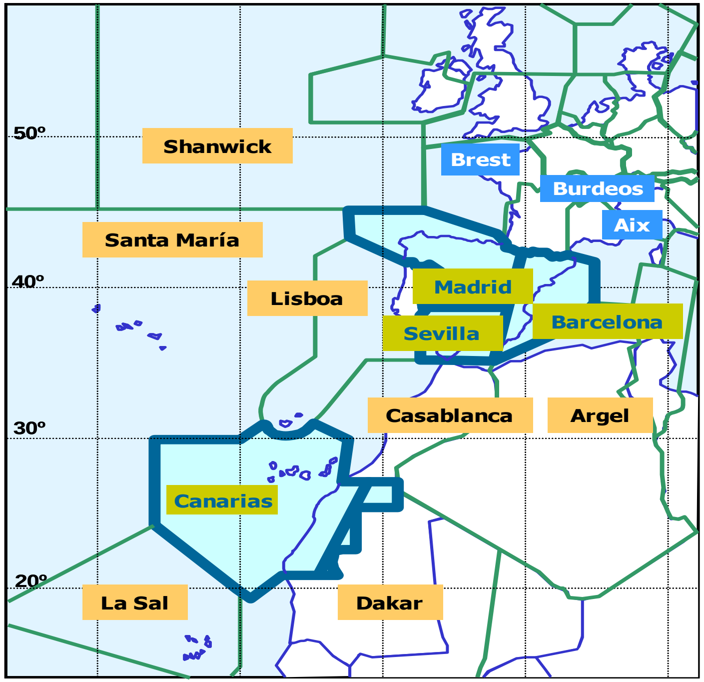
- ICAO : “Integrated set of regulations and activities established by a State aimed at managing civil aviation safety”
- Support strategic decision-making in adopting better decisions when allocating scare resources to higher safety risk areas
- To implement preventive approach for safety oversight and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



SPANISH AVIATION SYSTEM

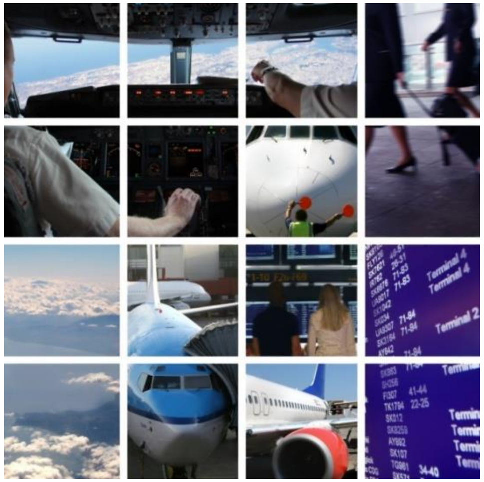
- Aircraft Design and Production 14
- Airlines 88
- Aerial Work Companies 219
- Aircraft Maintenance Org. >150
- Training Organizations 117
- Aircraft (total) 6,400
- Licensed personnel >40,000
- 232 airfields (47 airports)
- 62 ATM dependencies
- 340 Air Navigation Aids

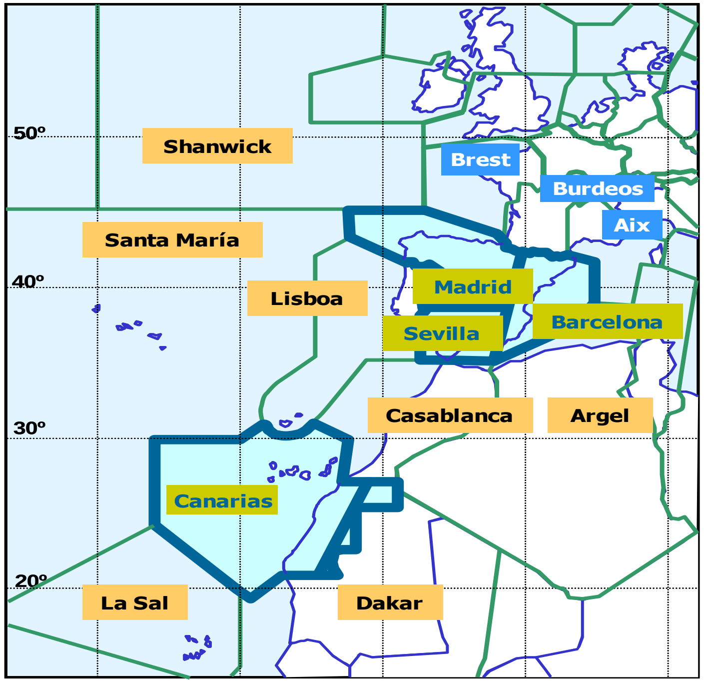




SPANISH AVIATION SYSTEM (2014)

- Operations 7311006
- Safety events 15394
- Accidents 42
- Safety events (type A) 453
- Accidents (type A) 10





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 industry and regulators have implemented little modern DA, RA, BS methodologies beyond risk matrices…

Agenda

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❑ SAFETY RISK AREAS/ISSUES

88 types of occurrences. Registered in ECCAIRS. Reporting 'compulsory'.
Other databases: ASN, Eurocontrol, DOT, ESTOP,…

- Flight operations
    - Hard landing,…

- Navigation services
    - TCAS warnings,…

- Aeronavigability
    - Motor failure,…

- Airport
    - Impact with vehicle,…

- External factors
    - Bird strike,…

5 severity degrees (ICAO and EUROCONTROL)
Minor, Significant, Major, Serious, Accident

4 types of aircrafts T1, T2, T3, T4 (No. of passengers)

METHODOLOGY

(Continuously) improve safety in Spanish skies

- Incident forecasting
  - Number of incidents
  - Severity of incidents
- Incident consequence forecasting
- Incident consequence assessment
- Usage
  - Monitoring
  - Screening, via risk mapping (and matrices)
  - Resource allocation

- Detailed analysis of chosen incidents

INCIDENT FORECASTING

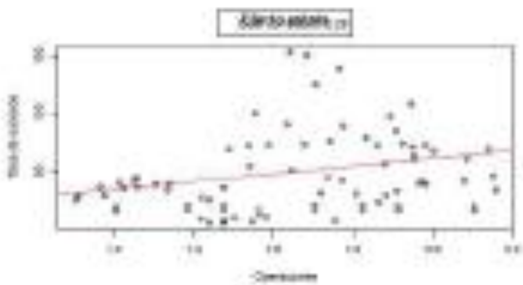
- (Non-homogeneous) Poisson processes

- Dynamic number of operations
- Dynamic rate

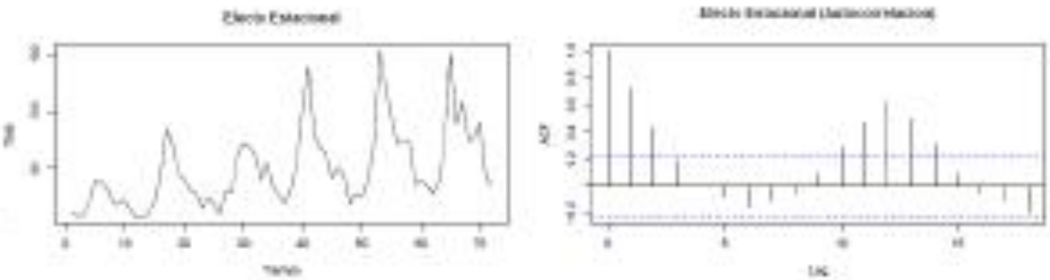
- Expert prior elicitation

- Forecasting incidents
  - Annual forecasts for risk assessment and management
  - Monthly, Weekly forecasts for tracking incidents, alarm setting

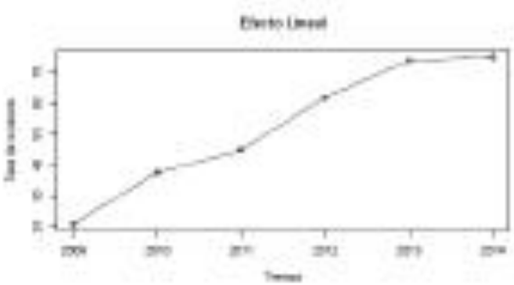
INCIDENT RATES. FEATURES



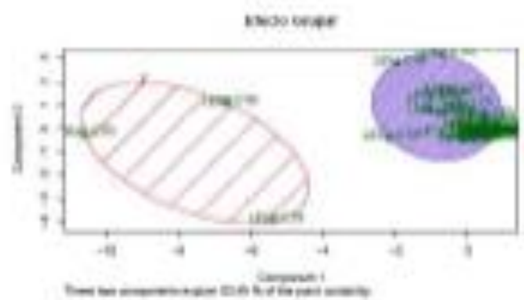
(a)Stress



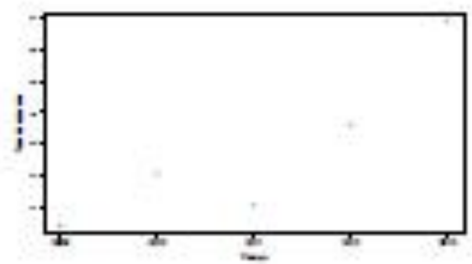
(b)Seasonal



(c)Linear

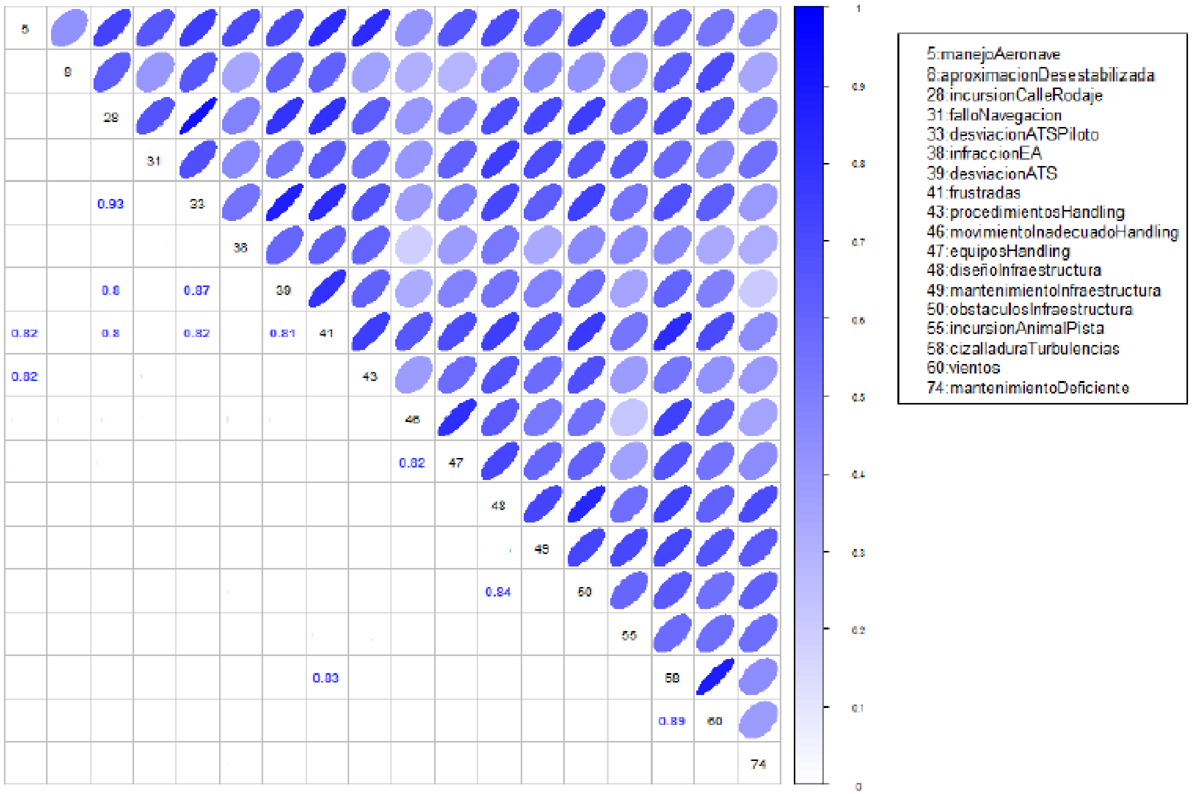


(d)Group



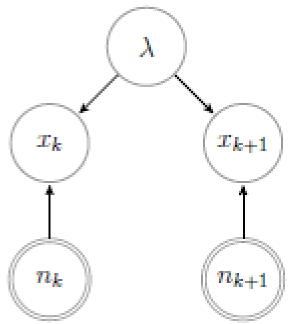
(e)Underreporting

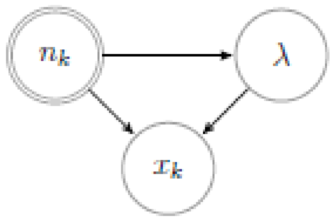
❑ INCIDENT RATES. FEATURES



INCIDENT FORECASTING. Models

ID





Model

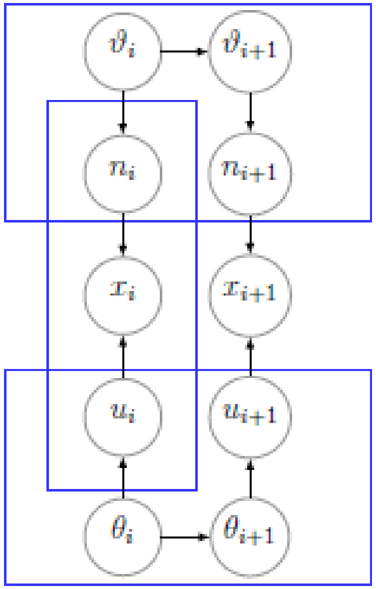
$$X_k|\lambda, n_k \sim Po(n_k\lambda)$$
$$\lambda \sim Ga(a,p).$$

$$\begin{aligned} X_k|\lambda, n_k & \sim Po(\lambda n_k), \\ \lambda = an_k + b + \epsilon_k, & \; \epsilon_k \sim N(0,\sigma^2), \\ p(a,b,\sigma^2) & \propto \tfrac{1}{\sigma^2}. \end{aligned}$$

$$\begin{aligned} x_k^i|\lambda^i, n_k^i & \sim \mathrm{Po}(\lambda^i n_k^i) \\ \lambda^i & \sim \mathrm{Ga}(a^i, p^i) \\ a^i & \sim \mathrm{Ga}(\alpha,\beta) \\ p^i & \sim \mathrm{Ga}(\gamma,\delta) \end{aligned}$$

INCIDENT FORECASTING. Models

- **ID**

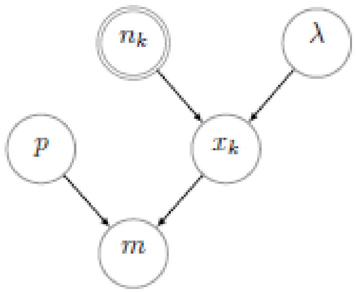


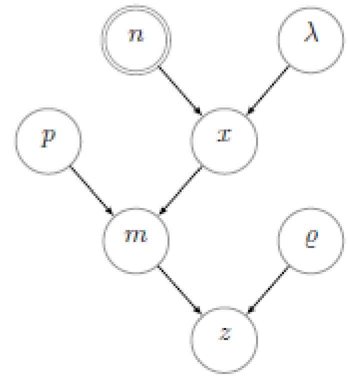
- **Model**

$$
\begin{cases}
\begin{cases}
\begin{cases}
n_i = H_i \vartheta_i + z_i, \; z_i \sim N(0, \Sigma_i) \\
\vartheta_i = J_i \vartheta_{i-1} + \xi_i, \; \xi_i \sim N(0, S_i)
\end{cases} \\
\vartheta_0 \sim N(\eta_0, S_0)
\end{cases} \\
x_i | \lambda_i, n_i \sim Po(\lambda_i n_i) \\
\lambda_i = \exp(u_i) \\
\begin{cases}
\begin{cases}
u_i = F_i \theta_i + v_i, \; v_i \sim N(0, V_i) \\
\theta_i = G_i \theta_{i-1} + w_i, \; w_i \sim N(0, W_i)
\end{cases} \\
\theta_0 \sim N(\mu_0, W_0),
\end{cases}
\end{cases}
$$

INCIDENT SEVERITY FORECASTING. UNDEREPORTING

- **ID**





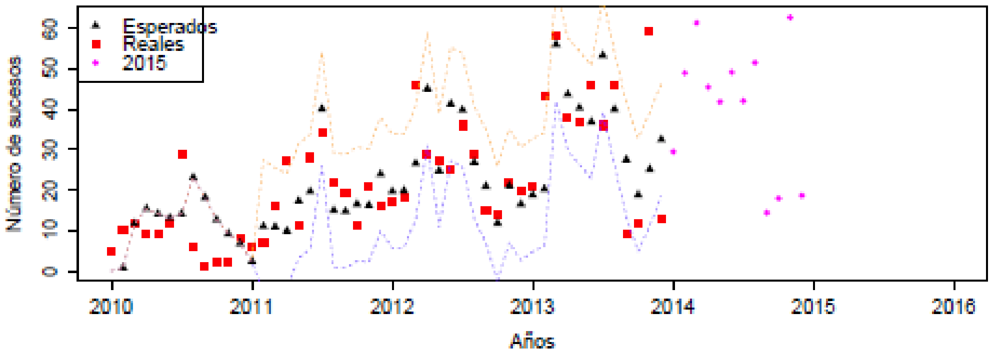
- **Model**

$$\lambda \sim Ga(a, p),$$
$$X_k \sim Po(\lambda n_k),$$
$$p \sim \mathcal{D}ir(\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5),$$
$$m | p, X_k \sim \mathcal{M}(X_k; p_1, p_2, p_3, p_4, p_5).$$

$$\varrho = (\varrho_1, \varrho_2, \varrho_3, \varrho_4, \varrho_5), \text{ con } \varrho_i \in [0, 1], \quad \mathcal{B}e(\alpha_i, \beta_i).$$

$$z = (z_1, z_2, z_3, z_4, z_5) \quad z_i \sim \text{Bin}(m_i, \varrho_i).$$

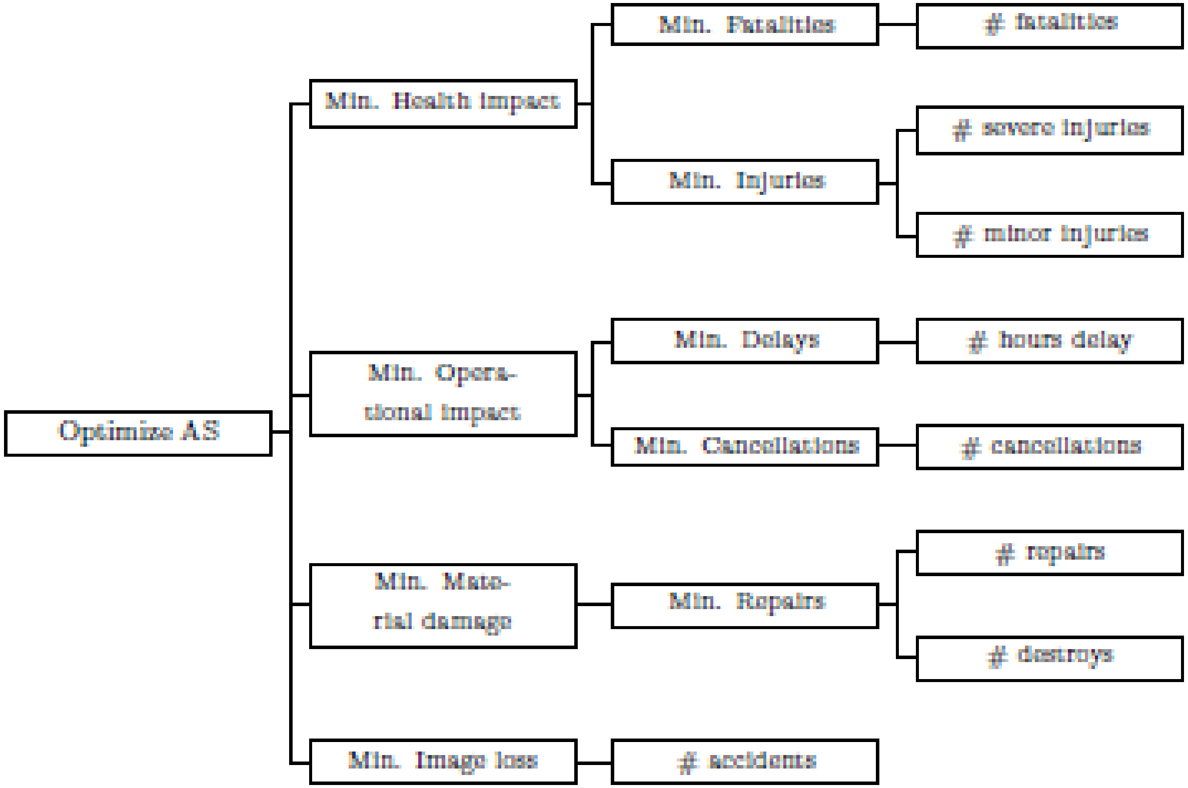
USES: FORECASTING AND MONITORING



m'	σ'	α'_1	α'_2	α'_3	α'_4	α'_5
19.48	10.68	2	4	27	1055	99

❑ FORECASTING INCIDENT CONSEQUENCES

✈ Multiattribute hierarchy



FORECASTING DEATHS

For a given type of event and aircraft

$$n_F = p_F \cdot q \cdot M$$

$$p_F \sim \tau_1 I_0 + \tau_2 \mathcal{B}e(a,b) + \tau_3 I_1$$

$$(\tau_1, \tau_2, \tau_3)|datos \sim \mathcal{D}ir(a_1 + \vartheta_1^1, a_2 + \vartheta_2^1, a_3 + \vartheta_3^1)$$

- Prop. fatalities
- Occup.
- Max. occ

$$p_F|D_g \sim \mathcal{B}e\left(a + \sum_{i=1}^{g} \eta_{F_i}, b + \sum_{i=1}^{g} (o_i - \eta_{F_i})\right)$$

$$q|datos \sim \mathcal{B}e\left(c + \sum_{i=1}^{f} p_{O_i}, d + \sum_{i=1}^{f} (1 - p_{O_i})\right)$$

ASN

	ϑ_1^1	ϑ_2^1	ϑ_3^1	$\hat{\tau}_1$	$\hat{\tau}_2$	$\hat{\tau}_3$	a	b	c	d	$\hat{q}$	$\hat{p}_F$
T1	36	57	241	0.11	0.17	0.72	269	487	136.58	199.42	0.41	0.78
T2	25	94	270	0.07	0.24	0.69	1509	1106	163.19	227.81	0.42	0.83
T3	3	22	142	0.02	0.18	0.8	2185	647	83.79	95.21	0.47	0.94
T4	4	14	60	0.06	0.19	0.75	1464	124	22.74	57.26	0.29	0.93

→ **Statistical value of life. EUROCONTROL**

❑ EVALUATING CONSEQUENCES. Utility... Loss

$$(n_{vm}, n_h, t_d, n_c, n_{rm}, s_1),$$

Image costs

$$v(n_{vm}, n_h, t_d, c_c, n_{rm}, d_{img}) = -c_{vm} n_{vm} - \sum_{i=1}^{2} c_h^i n_h^i - c_d t_d - c_c n_c - (c_{rm}^1 n_{rm}^1 + c_{rm}^2 n_{rm}^2) - c_{img} s_1$$

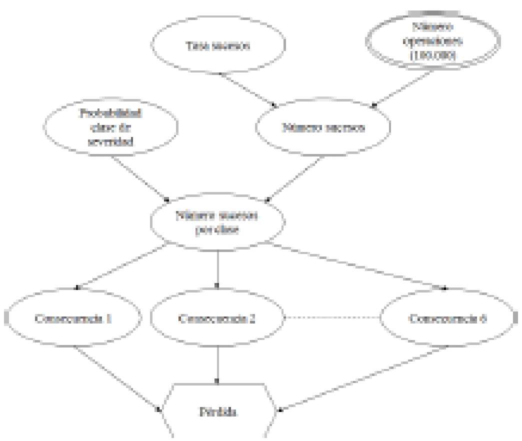
$$u(v) = -\exp(kv)$$

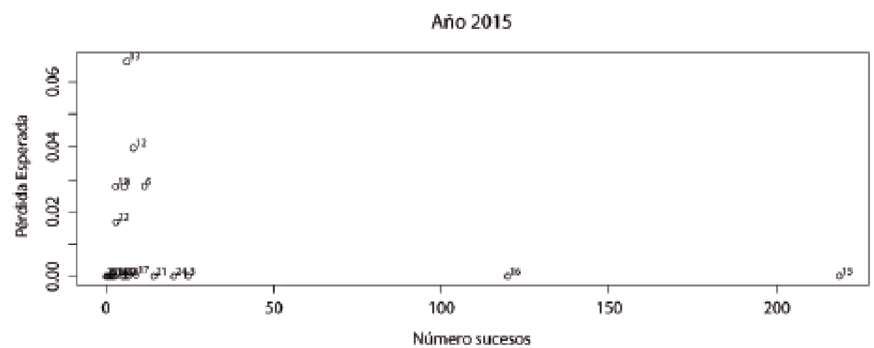
$$l_2(v) = a + b\exp(kv),$$

RISK MAPPING

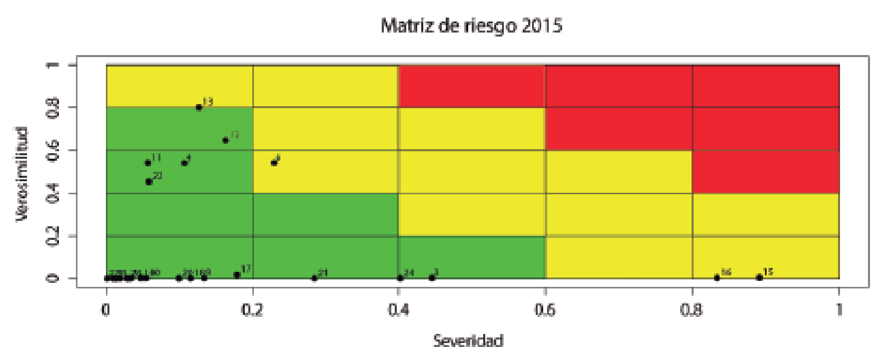
- **Mapping (forecasted) incident numbers vs (forecasted) incident costs** (expected, boxplots)

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



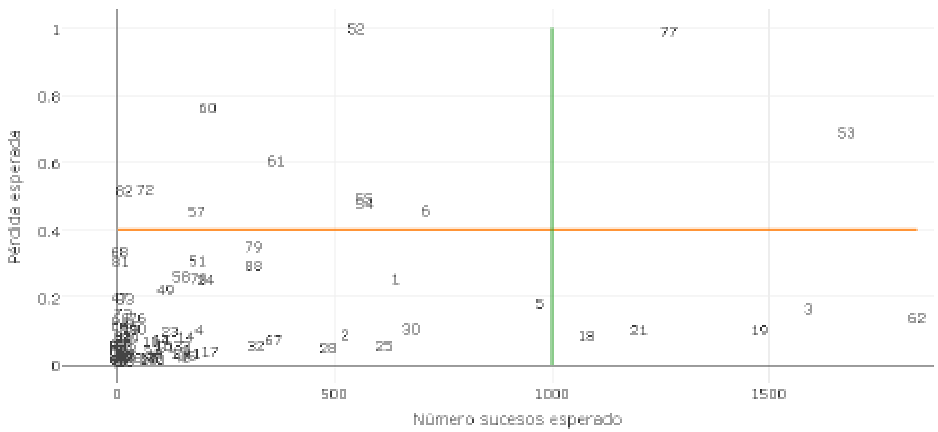


(a)



(b)

❑ USES: SCREENING



<table>
<tr><th>Anti-Pareto</th><th>Más costosos</th><th>Más frecuentes</th><th>Empeora</th><th>Emergentes</th></tr>
<tr><td rowspan="2">(52)</td><td>(6)</td><td>(3)</td><td rowspan="2">(19)</td><td rowspan="11">(60)</td></tr>
<tr><td>(52)</td><td>(18)</td></tr>
<tr><td>(53)</td><td>(53)</td><td>(19)</td><td rowspan="2">(62)</td></tr>
<tr><td>(62)</td><td>(54)</td><td>(21)</td></tr>
<tr><td rowspan="7">(77)</td><td>(55)</td><td>(53)</td><td rowspan="7">(77)</td></tr>
<tr><td>(57)</td><td>(62)</td></tr>
<tr><td>(60)</td><td rowspan="5">(77)</td></tr>
<tr><td>(61)</td></tr>
<tr><td>(72)</td></tr>
<tr><td>(77)</td></tr>
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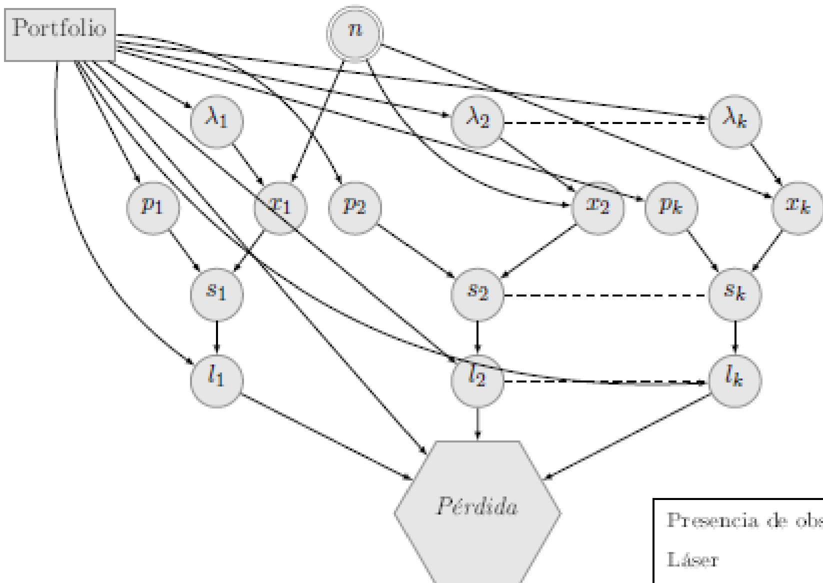
</table>

	Suceso	Ref.	ADREP
1	Presencia de obstáculos / FOD	123	ADRM
2	Láser	-	-
3	Golpes de aves	651	BIRD
4	Incursión aeronave en otras superficies	321-1	RI-VA(P)
5	Fallos de sistema motor	441	SCF-PP
6	Fallos de sistema NO motor	431	SCF-NP
7	Turbulencias meteorológicas	621	TURB
8	Vientos	622	OTHR
9	Colisión con aves	651	BIRD
10	Toma de tierra dura, pesada, rápida o larga	231	ARC
11	Manejo de la aeronave	2121	OTHR
12	Cizalladura	612	WSTRW
13	Cizalladura en cabeceras	-	-
14	Fallos técnicos sin identificar	451	OTHR
15	Otras condiciones meteorológicas	641	OTHR/UIMC
16	Pérdida de control en vuelo	282	LOC-I

USES: RESOURCE ALLOCATION



$$\text{máx} \quad v(z)$$

s.a.

$$\sum_{i=1}^{16} z_i = 0.48$$

$$0.015 \leq z_i \leq 0.3, \; i = 1, \ldots, 16$$

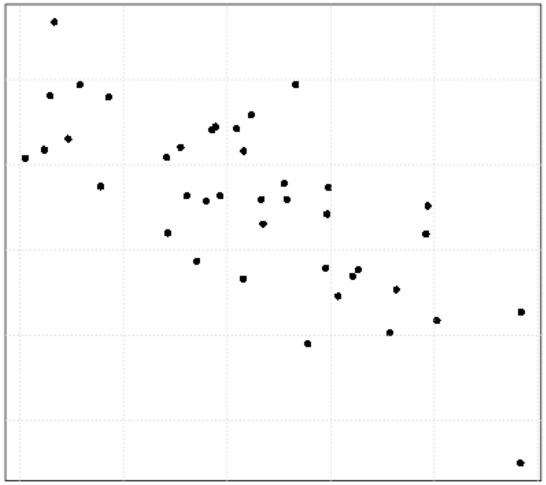
	Tasa máx	Tasa act	Tasa mín	δ^j	ρ^j	κ^j	% Insp.
Presencia de obstáculos / FOD	97.2	87.37	37.1	36.62	60.58	15.58	1.5
Láser	75.3	59.27	12.2	12.18	63.12	25.78	1.5
Golpes de aves	91.2	81.12	31.5	31.1	60.1	16.16	1.5
Incursión aeronave en otras superficies	75.98	65.2	20.7	20.55	55.43	19.03	1.5
Fallos de sistema motor	70.5	57.28	24.2	14.2	46.3	29.58	14.36
Fallos de sistema NO motor	200.5	174.86	40.6	39.16	161.34	15.23	15.18
Turbulencias meteorológicas	28.2	21.65	4.6	4.6	23.6	28.6	11.4
Vientos	50.2	37.92	14.6	14.6	35.6	37.23	7.94
Colisión con aves	212.3	191.77	46.2	40.93	171.37	11.23	1.5
Toma de tierra dura, pesada, rápida o larga	8.63	6.7	0.72	0.72	7.91	24.6	11.57
Manejo de la aeronave	178.2	132.37	20.72	20.71	157.49	30.26	13.44
Cizalladura	82.45	59.19	25.96	25.96	56.49	46.69	5.65
Cizalladura en cabeceras	58.45	38.89	15.37	15.37	43.08	53.26	1.5
Fallos técnicos sin identificar	75.25	59.19	34.84	34.84	40.41	44.58	5.59
Otras condiciones meteorológicas	31.13	18.81	11.26	11.26	19.87	85.15	3.62
Pérdidas de control en vuelo	1.78	1.39	0.62	0.62	1.16	36.06	2.25

DECIDING ON INTERVENTIONS

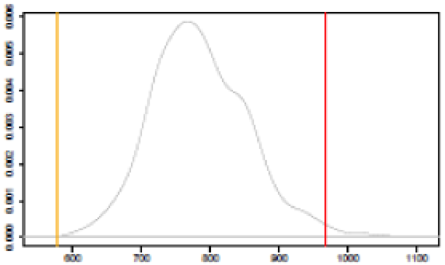
- Pick those in the anti-Pareto frontier
- Pick some of those more costly
- Pick some of those more frequent
- Pick those that go worse
- Pick novel issues

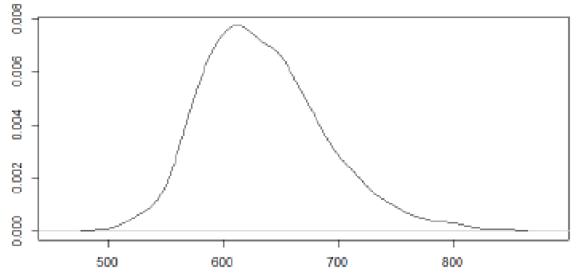
- Relate with resource allocation

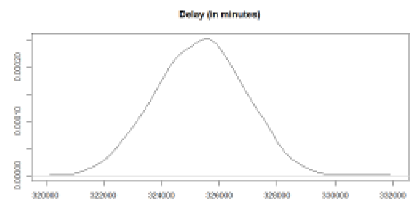
- Screened by experts
- Finally decided by politicians

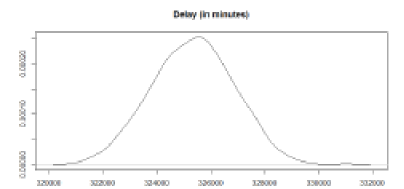


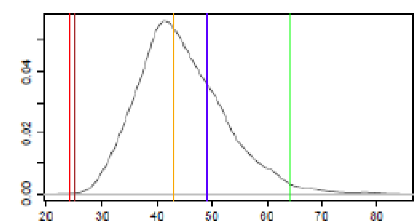
❑ RESULTS

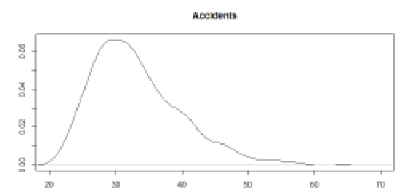


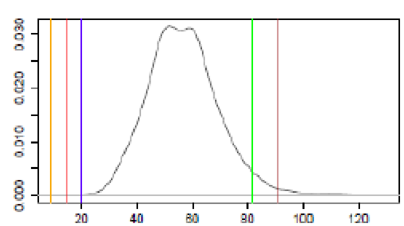

0.008
0.006
0.004
0.002
0.000
500
600
700
800

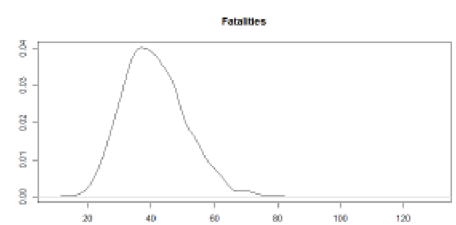

Delay (in minutes)


Delay (in minutes)


0.04
0.02
0.00
20
30
40
50
60
70
80


Accidents


0.030
0.020
0.010
0.000
20
40
60
80
100
120


Fatalities

DETAILED ANALYSIS FOR SOME INCIDENTS

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

MOTOR FAILURE

- **Effects affecting rates**
- **Cluster of companies**
- **Consequences**
- **Resource allocation among and within clusters**

❑ UNINTENDED SLIDE DEPLOYMENT

Changed in procedures

FUEL FOR HOLDING

- Competition forces companies to reduce costs, without jeopardising safety.
- Fuel costs more than 25% DOC
- ATFM delays at congested airports.
- Airline fuel policies and regulatory requirements should ensure every flight carries enough fuel for planned route, and additional reserve to cover deviations; e.g. ATFM delays.
- When delays at destination, holding may be required by ATC.
- Flight crew will be able to hold depending on remaining fuel quantity. Inability to hold will cause divert to alternative airport. It entails significant DOCs.

- Model to provide optimal F4H

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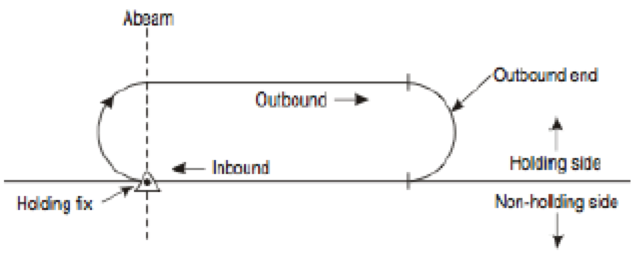
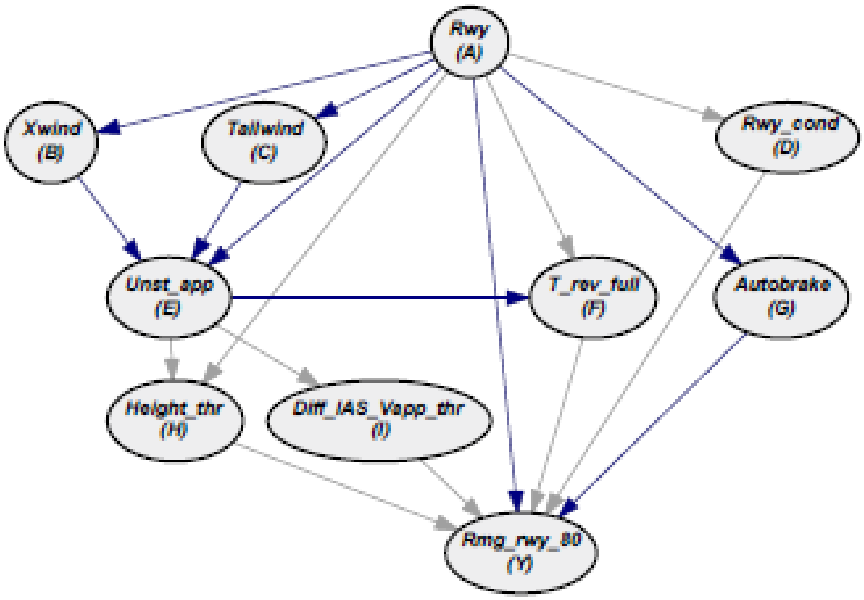


❑ RUNWAY EXCURSION

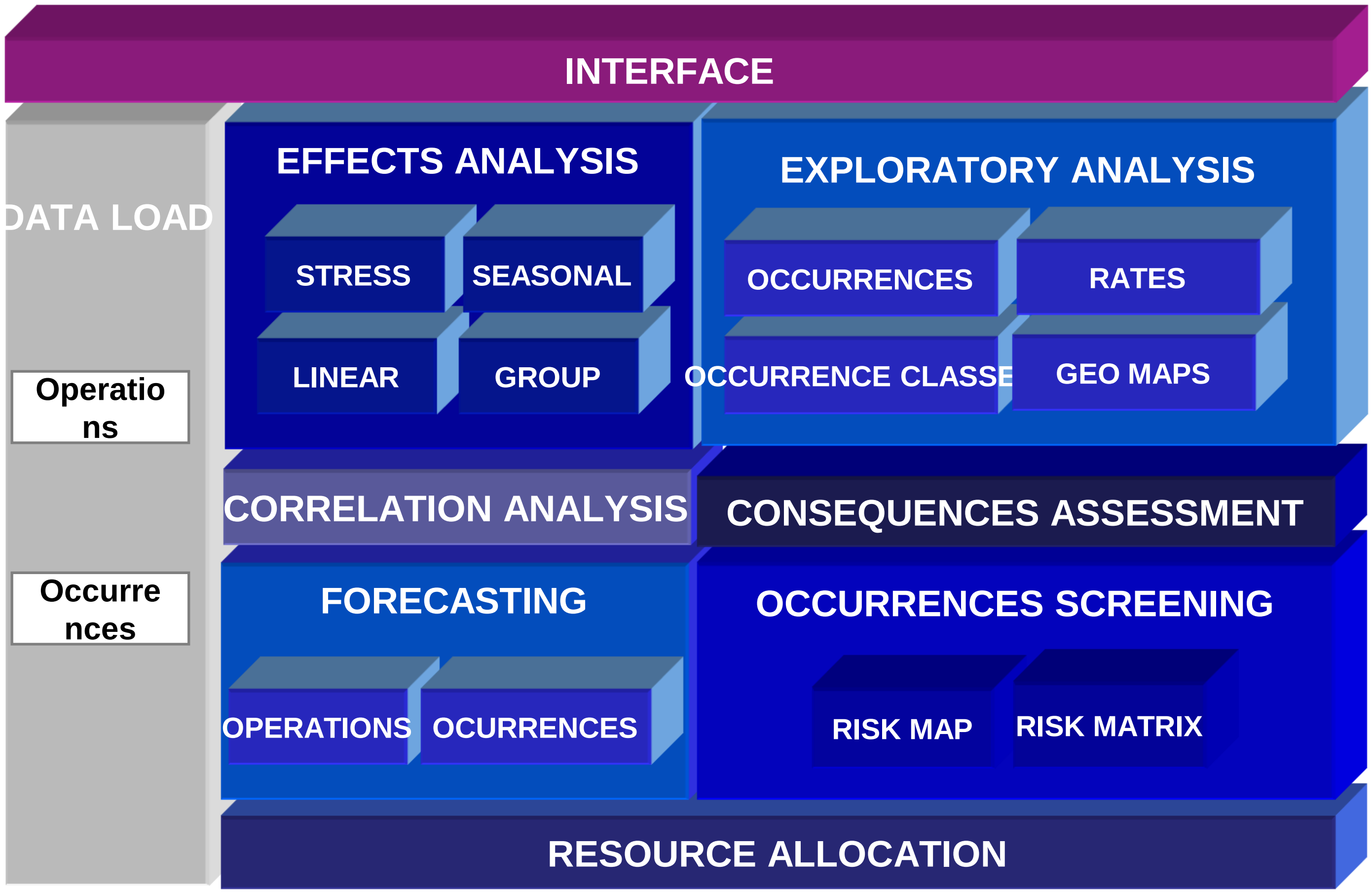


Some recommendations

Agenda

- Safety in Air Transportation
- Elaborating the State Safety Program
- **RIMAS (Risk Management in Aviation Safety)**
- Discussion

RIMAS

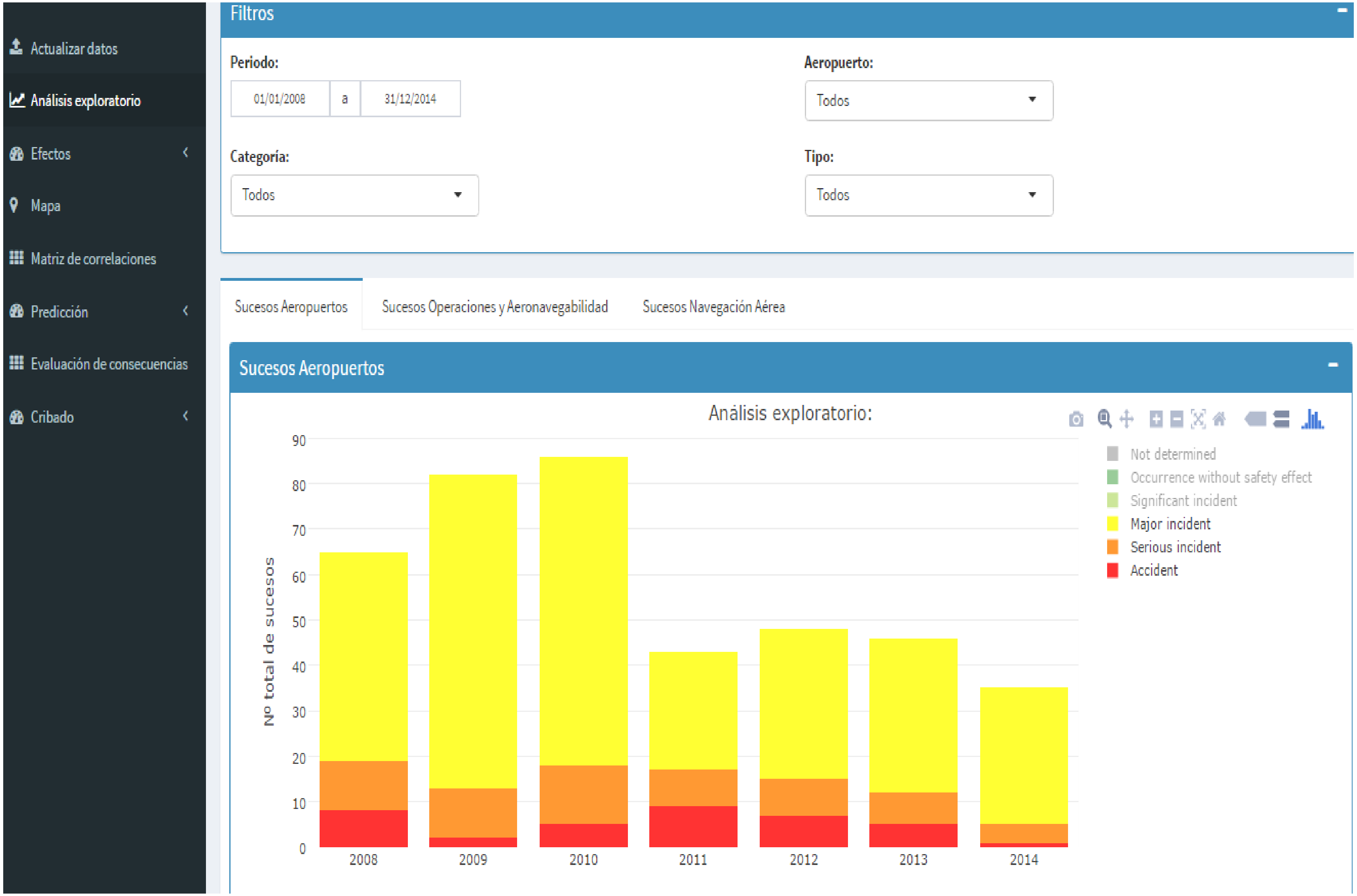


R: diplyr, plotly, leaflet, DT, Shiny, dlm,….

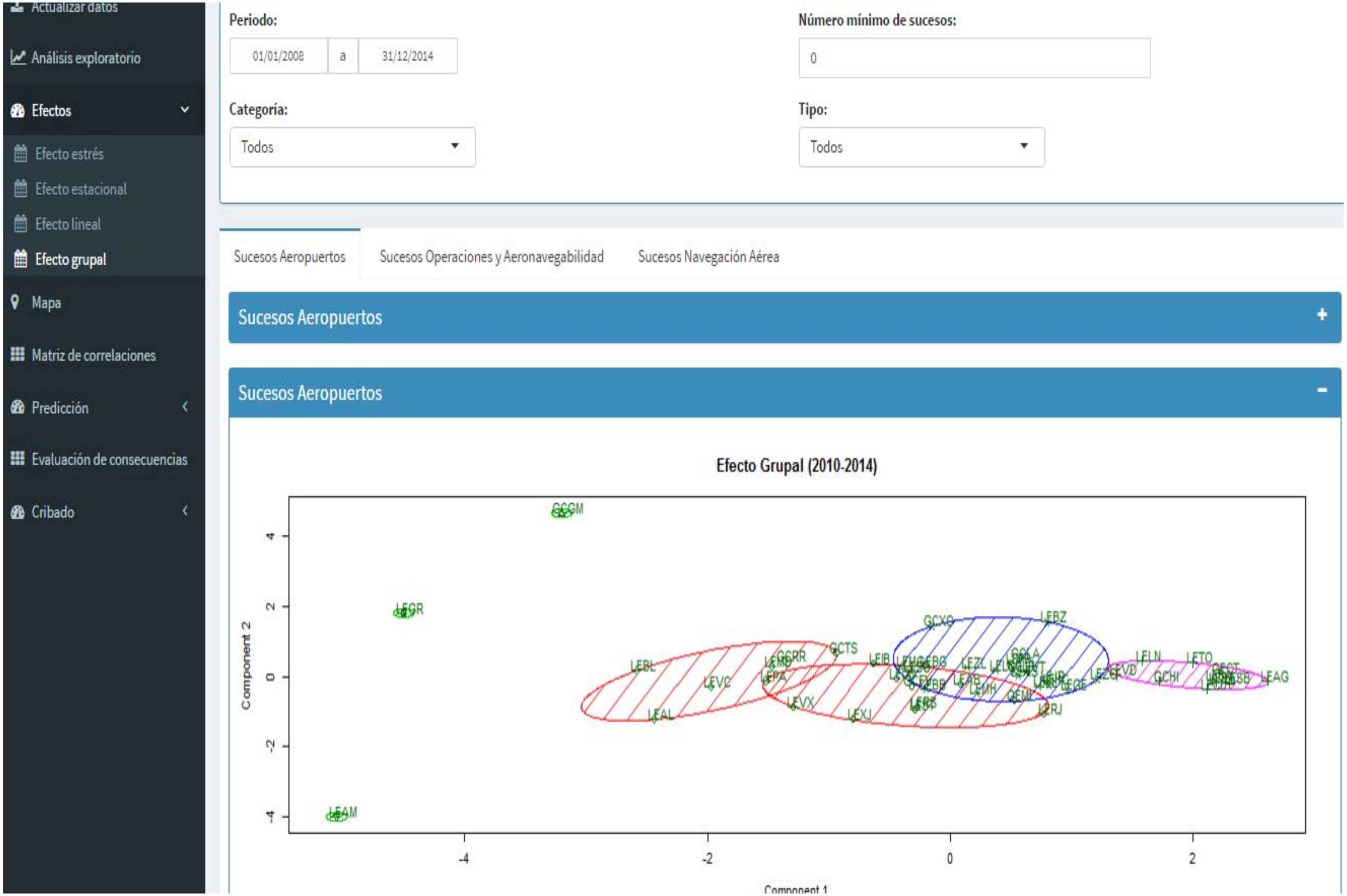
RIMAS

- Forecasting models for numbers of various types of occurrences
- Forecasting models for occurrence severity classes
- Forecasting models for consequences
- Construction of multiattribute utility function to assess such consequences of occurrences
  - Monitoring
  - Screen riskier occurrences
  - Assigning resources optimally to mitigate aviation hazards
  - Reporting

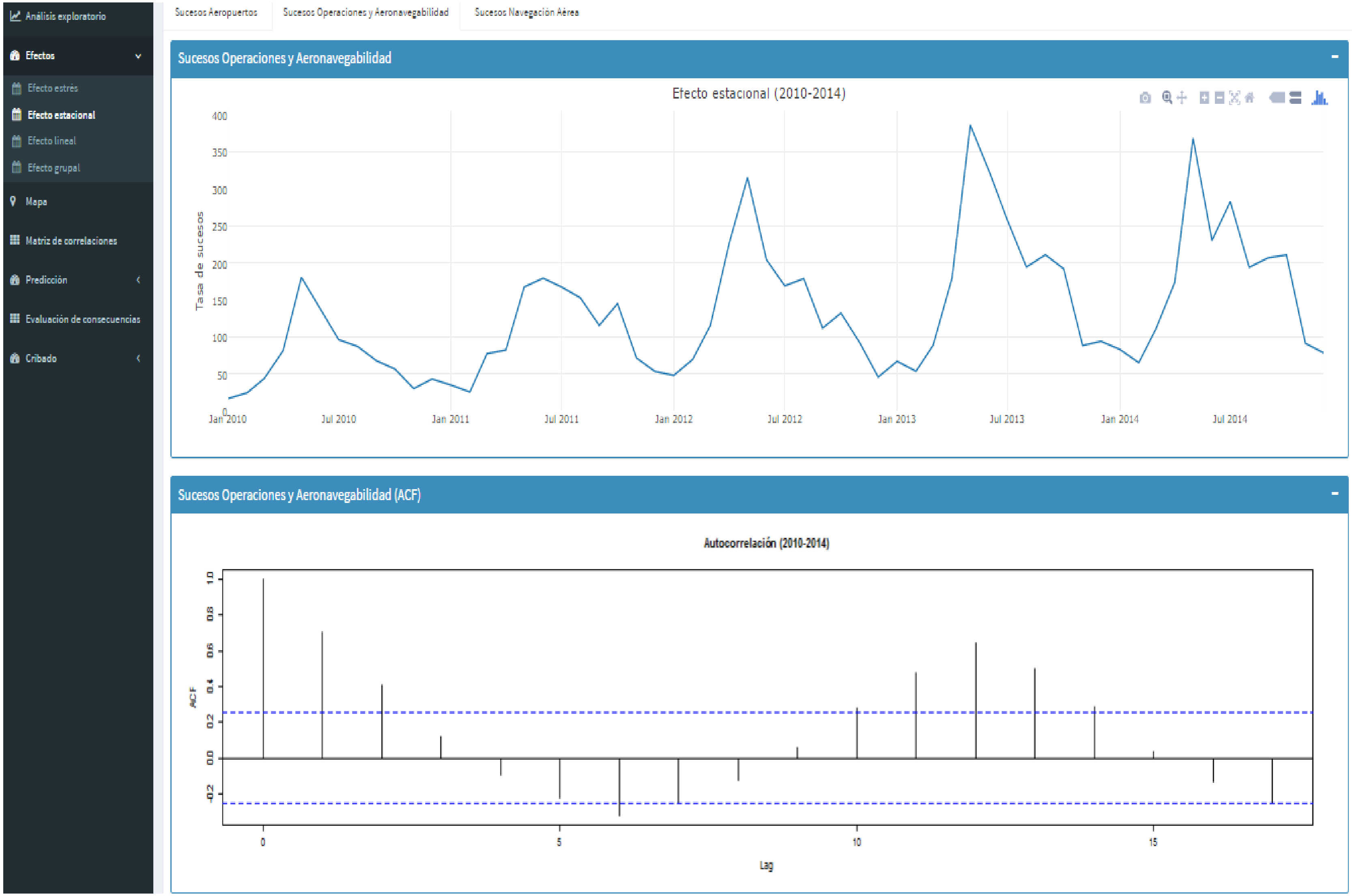
EXPLORATORY ANALYSIS



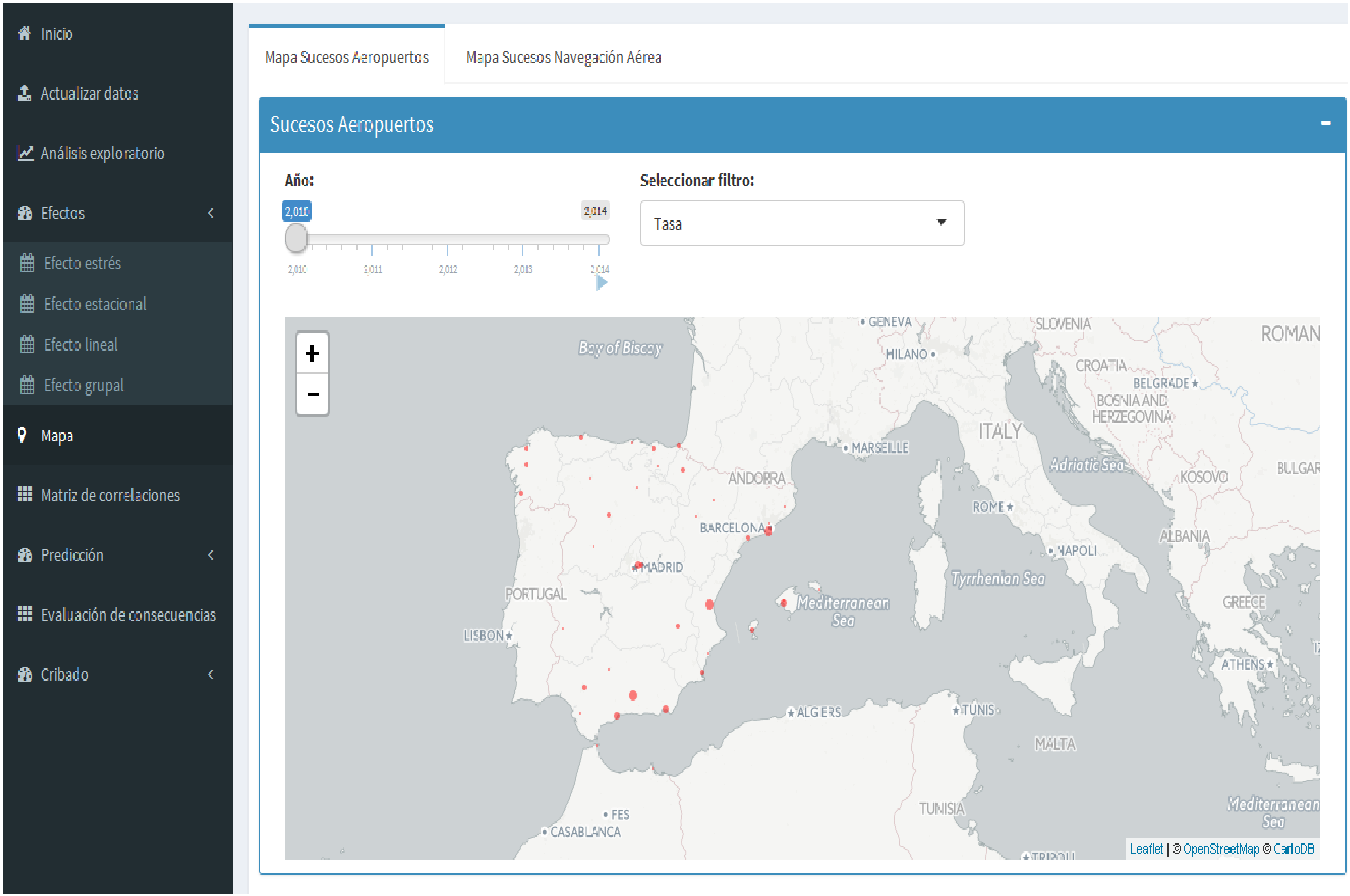
EFFECT ANALYSIS: GROUP



EFFECT ANALYSIS: SEASONAL



GEO MAPS



Inicio
Actualizar datos
Análisis exploratorio
Efectos
Efecto estrés
Efecto estacional
Efecto lineal
Efecto grupal
Mapa
Matriz de correlaciones
Predicción
Evaluación de consecuencias
Cribado
Mapa Sucesos Aeropuertos
Mapa Sucesos Navegación Aérea
Sucesos Aeropuertos
Año:
2,010
2,014
2,010 2,011 2,012 2,013 2,014
Seleccionar filtro:
Tasa
Bay of Biscay
GENEVA
MILANO
SLOVENIA
CROATIA
BELGRADE
BOSNIA AND HERZEGOVINA
ITALY
MARSEILLE
ANDORRA
Adriatic Sea
KOSOVO
BULGAR
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ROME
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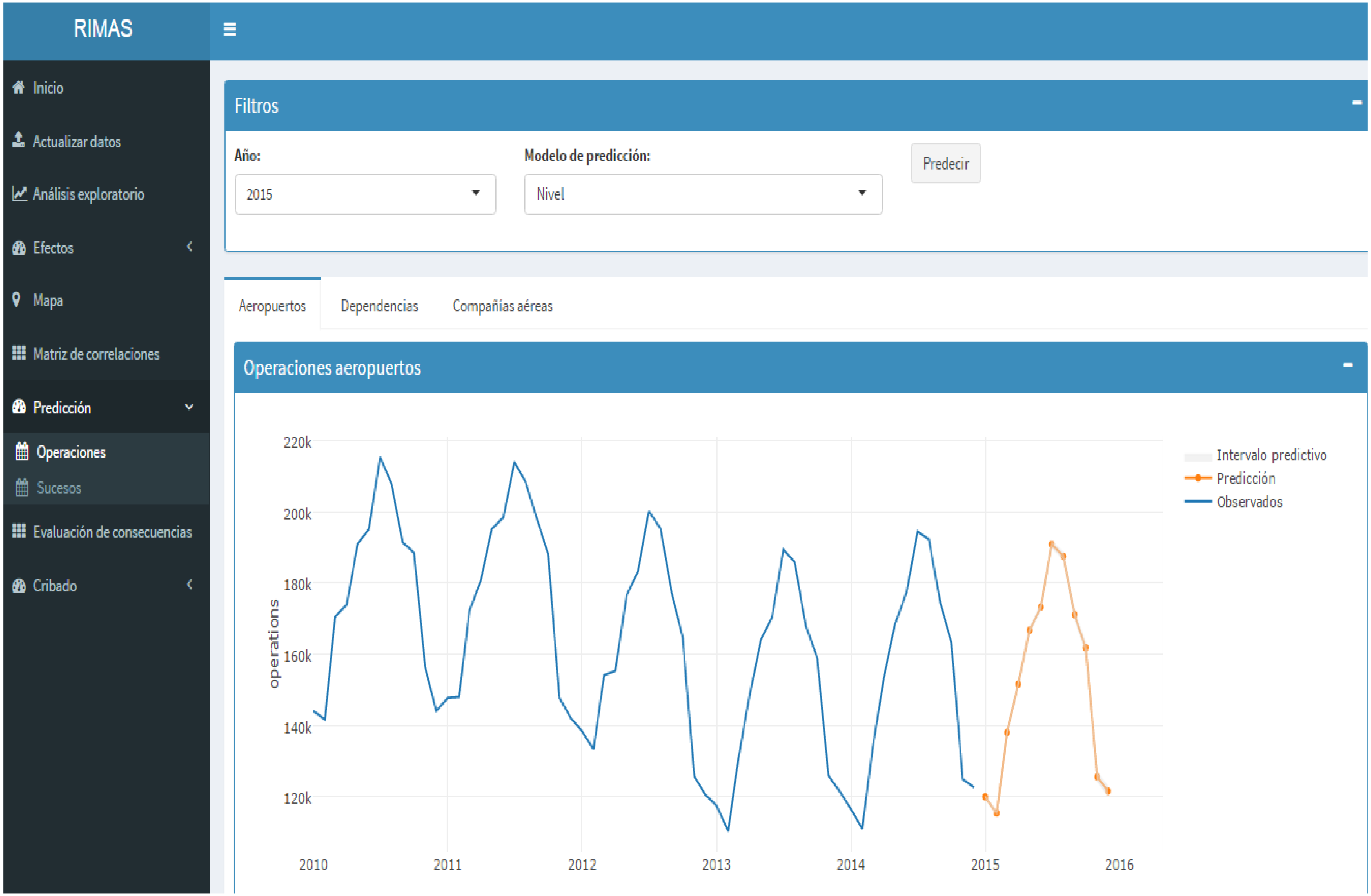
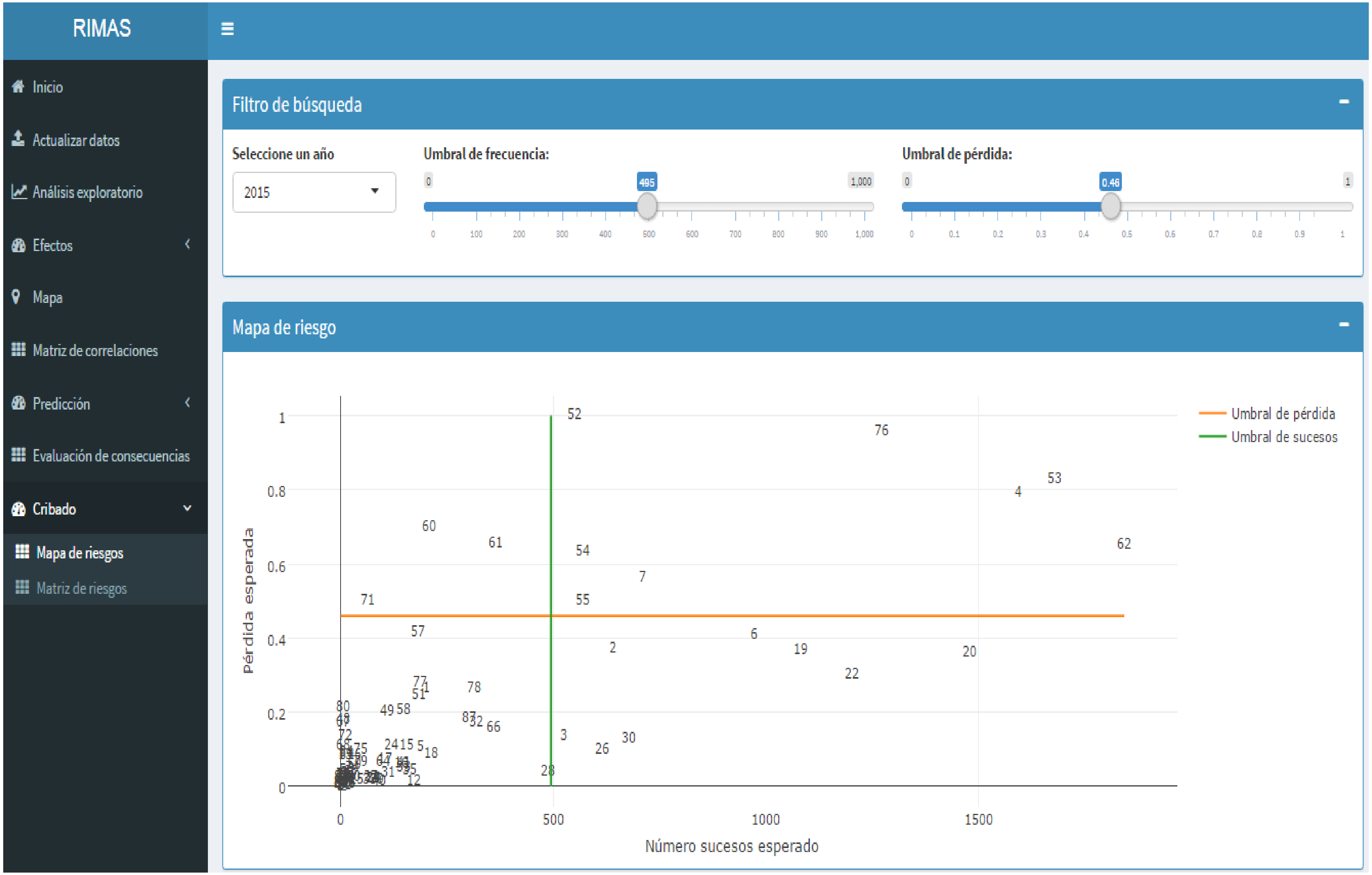
PORTUGAL
Mediterranean Sea
GREECE
LISBON
ATHENS
ALGIERS
TUNIS
MALTA
TUNISIA
FES
CASABLANCA
Leaflet | © OpenStreetMap © CartoDB

OPERATIONS FORECASTING



RISK MAP


RIMAS
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Evaluación de consecuencias
Cribado
Mapa de riesgos
Matriz de riesgos
Filtro de búsqueda
Seleccione un año
2015
Umbral de frecuencia:
495
Umbral de pérdida:
0.46
Mapa de riesgo
Umbral de pérdida
Umbral de sucesos
Pérdida esperada
Número sucesos esperado

Agenda

- Safety and Security in Air Transportation
- Elaborating the State Safety Program
- RIMAS
- **Discussion**

DISCUSSION

- R
- (Big Data), Large Data, Standard data, Little data, No data
- Industrial stats in action
  - Large volume for some variables
  - Not so large for others. Other data sources. Expert judgement
  - Used for decision support

- Through earlier collaboration with Iberia
- 2 year project, with several training periods
- Improving the forecasting models (with SGDLMs)
- Strong sponsor

DISCUSSION

- Exporting to other countries for their national agencies
- Exporting to aviation companies, other aviation services
- Exporting to other business.
- Big Data!   AERODATA
- Integrating Safety (RA) and Security (ARA)

See Banks et al (2015) Adversarial Risk Analysis

Thanks

Collabs welcome!!!

david.rios@icmat.es

SPOR DataLab ICMAT. https://www.icmat.es/spor/

ARAC. Asociación Amigos Real Academia Ciencias. http://arac.rac.es/

Aisoy Robotics. http://www.aisoy.es/

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