From risk analysis to adversarial risk analysis

Part V. Framework for risk analysis, with applications

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Framework for risk analysis

- Framework
- RA for a comercial aviation operational example

A framework for risk analysis: starting assumptions

- Only interested in costs…
- An existing alternative
- Just my organisation is relevant
- Aim. Maximise expected utility

Risk analysis framework

- Forecast **costs** under normal circumstances
- Identify hazard events, estimate probabilities and impacts on costs (additional induced costs)
- Forecast costs (**a “mixture” model**). Compute changes in expected utility. If too big,…
- Identify interventions, estimate impact on probabilities and/or costs.
- Compute expected utilities. Choose best intervention (if gain is sufficient)

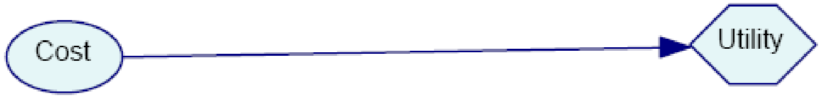
Basic setting

- Design given (no interventions, status quo)
- (Random) costs are identified
- Expected utility computed

$$\Psi = \int u(c)\pi(c)dc$$

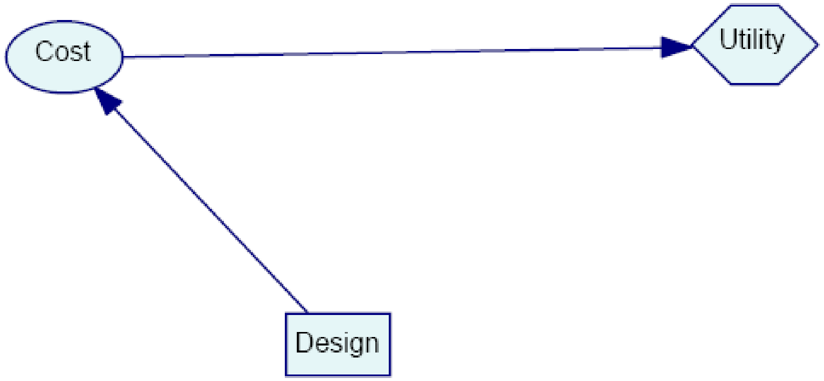
Basic setting

- Design given



$$\Psi = \int u(c)\pi(c)dc$$

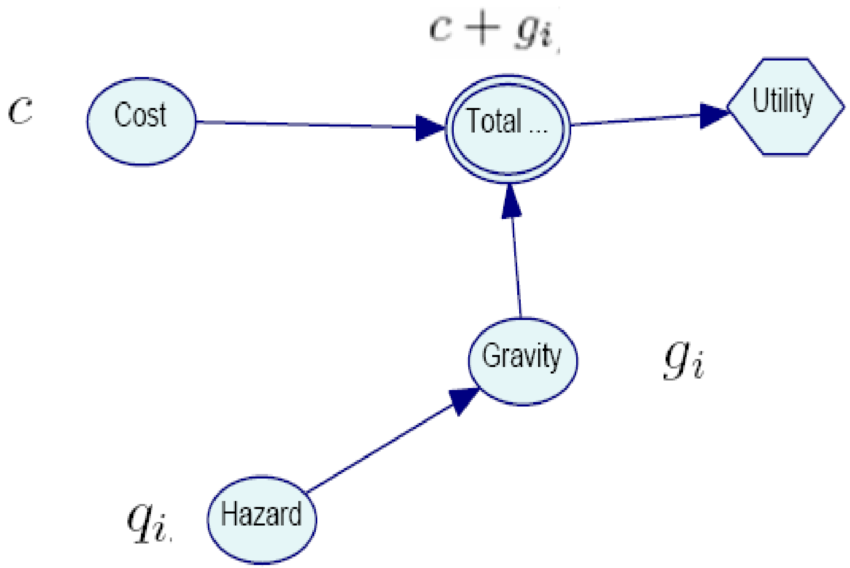
- Including design choice



$$\max_a \Psi(a) = \int u(c)\pi(c|a)dc$$

Risk assessement

- Likelihood and impact of identified hazards. They happen with a certain probability and entail an additional cost



- Compute expected utility after risk assessed:

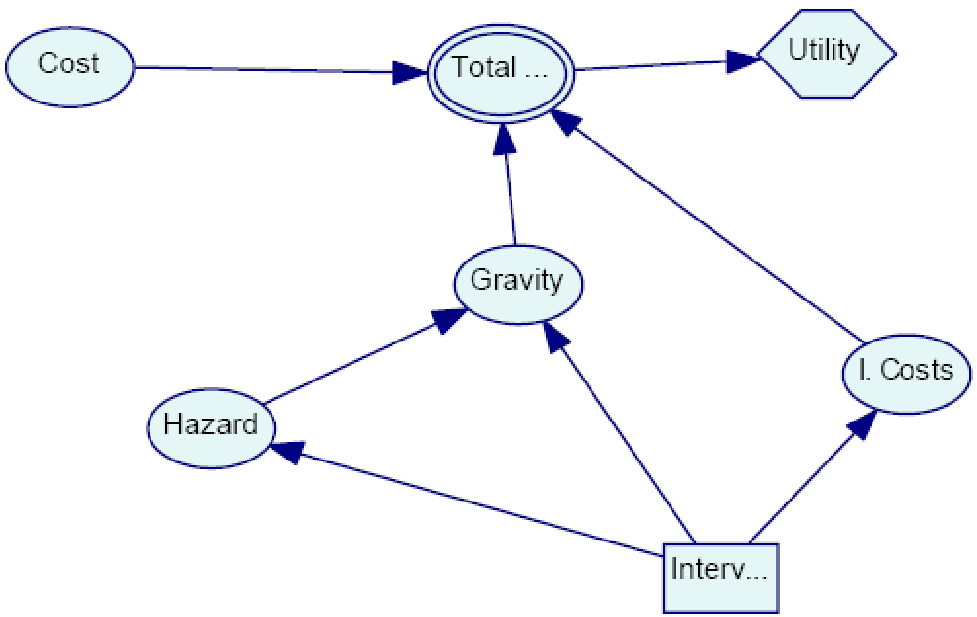
$$\Psi_r = \int\int\int\sum q_i u(c+g_i)\pi(q)\pi(g)dqdg \ \ \pi(c)dc$$

- Impact of risks: $\Psi - \Psi_r$

If impact is too high, we need to manage risks

Risk management

- Intervention to be chosen:



Interventions tend to reduce the likelihood of hazard appearance and its gravity... but they also entail a cost

$$\Psi_d = \max_d \Psi_r(d) = \max_d \int\int\int\int\sum q_i u(c+g_i+c_d)\pi(q|d)\pi(g|d)dq\, dg\pi(c)\pi(c_d)\ \ dc_d\, dc$$

- Gain through managed risk: $\Psi_d - \Psi_r$

Choose the intervention which provides the biggest gain, if it is sufficiently big...

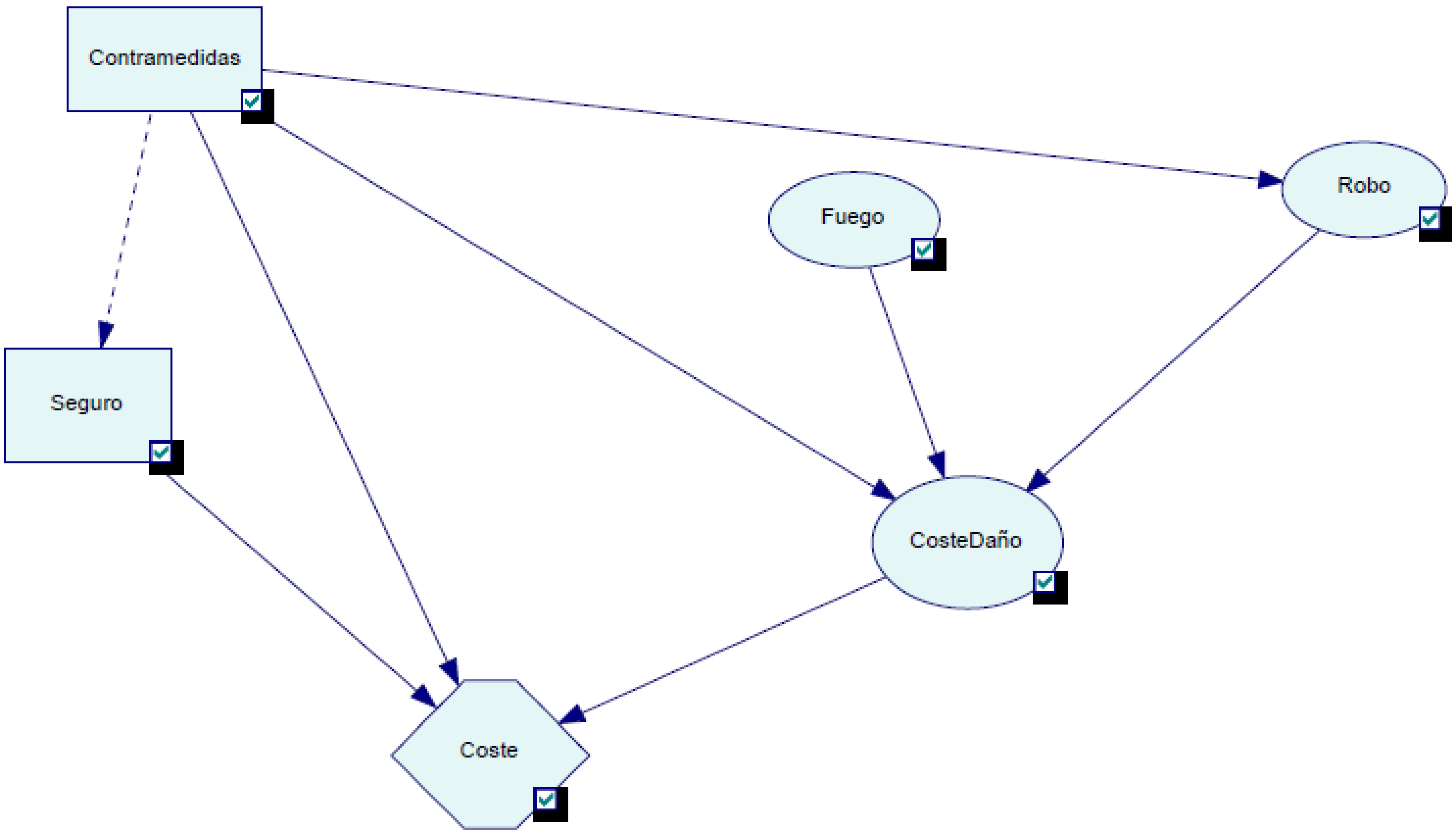
Risk analysis: A simple example

- Consider adopting countermeasures and buying insurance for a building.
- Threats: Nothing, Fire, Burglary
- Countermeasure:
  - Alarm. Less likely a burglary
  - Detector. Less severe a fire
  - No budget for both

Risk analysis: Simple example

- Insurance:
  - Covers all costs in relation with fire and burglary.
  - Cheaper if countermeasures implemented
- Involved quantities relatively small for organisation, risk neutral

Risk analysis: simple example



An example: Unintended slide deployment

An example from aviation operations. Background

- Safety critical in aviation industry
- Increasing competition forcing cost reduction, even more under crisis
- Relatively simple tools for risk analysis commercial aviation operations

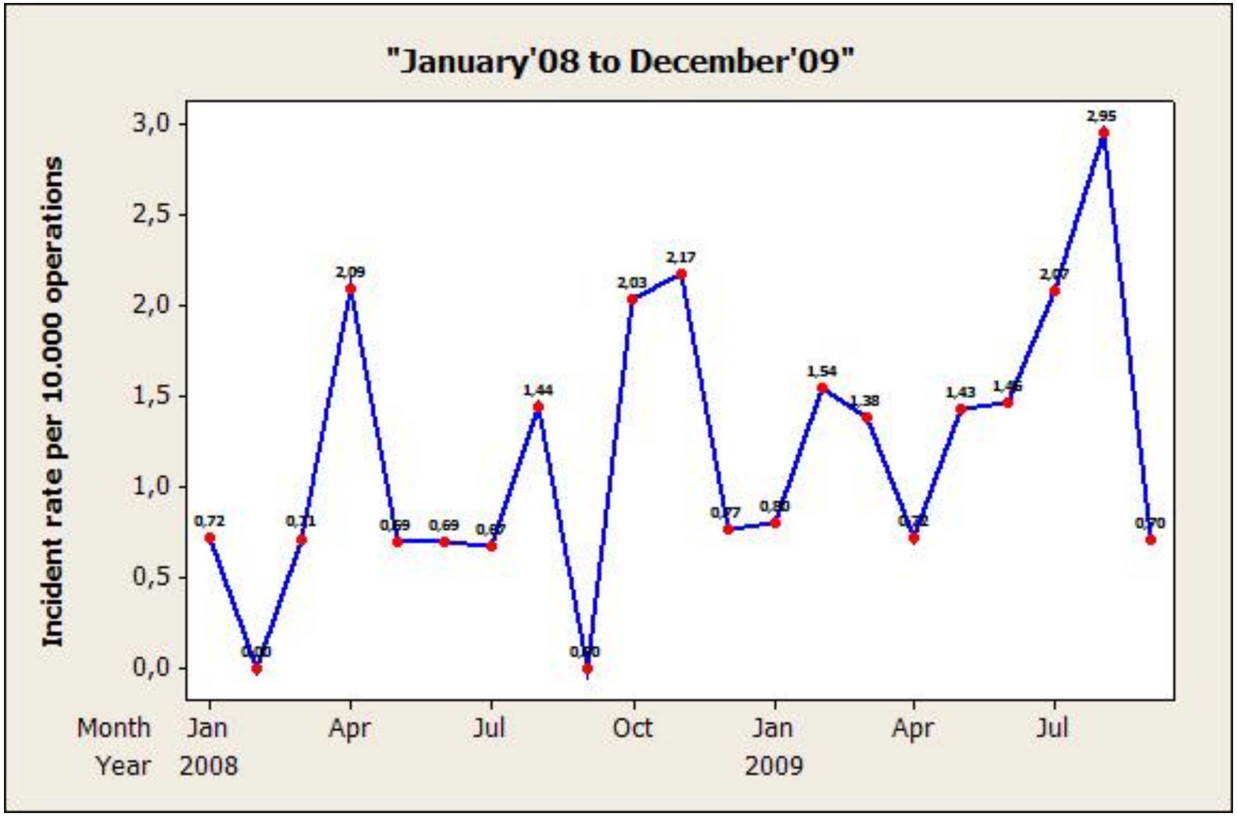
- Unintended slide deployment under normal operations within a comercial airline
- Inflatable slides to facilitate passenger evacuation in emergency situations
- (Expected??) cost 20 million USD/year for the whole industry (IATA, 2000)

An example: Unintended slide deployment

- Factors affecting incidents
- **Severity analysis (cost)**
- Risk assessment
- Countermeasures?
- Best countermeasure: risk management

- Estimated annual savings 600000 €

An example: Unintended slide deployment



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An example from aviation operations. Incident analysis

- The following potentially 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)

- A. 30000+ operations, 7 incidente
- B. 262000+ operatios, 28 incidents
- Probability interval for p_A-p_B [.00006,.0003]

Incident analysis

- Logistic regression model

$$(x_i, n_i, y_i), i = 1, ..., k$$

$$y_i|\theta_i \sim Bin(n_i, \theta_i)$$

$$logit(\theta_i) = \alpha + \beta x_i$$

Case	Operations	Incidents	Exp.Variables	Coding
i	n_i	y_i	(fleet,day,turn)	x_i
1	29702	3	B,Fst,1	1,1,1
2	59661	7	B,Fst,Oth	1,1,2
3	44159	6	B,Snd,1	1,2,1
4	46257	6	B,Snd,Oth	1,2,2
5	28910	2	B,Thrd,1	1,3,1
6	55193	4	B,Thrd,Oth	1,3,2
7	15245	6	A,Fst,1	2,1,1
8	1516	0	A,Fst,Oth	2,1,2
9	13713	1	A,Thrd,1	2,3,1

An example from aviation operations. Incident analysis

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)

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

An example: Unintended slide deployment

- Cost
  - Removal cost
  - Transportation cost
  - Repair cost
  - Ground delay associated costs

An example: Unintended slide deployment

- Removal Cost
  - Lab x T_m
  - $T_{m.}$ 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

An example: Unintended slide deployment

- Maintenance cost

$$C_m = q \times C_m^i + (1-q) \times C_m^e$$

- q assessed Beta (16,4)
- C_m

	Bf	Ba	Bw	B2/3
Int. costs	1840	1480	1630	1430
Ext. costs	2605	2323	4571	4741

	A1	A2	A3	A6	A6w
Int. costs	4160	4040	2400	3630	3210
Ext. costs	6429	4850	5785	7423	4946

	Bf	Ba	Bw	B2/3
Incidents	17	4	1	5
Parameters	18	5	2	6

	A1	A2	A3	A6	A6w
Incidents	4	2	1	0	0
Parameters	5	3	2	1	1

An example: Unintended slide deployment

- Costs in relation with delays

$$T_d = p_0 \; I_0 + p_1 \; F_d$$

$$p_0 + p_1 = 1$$

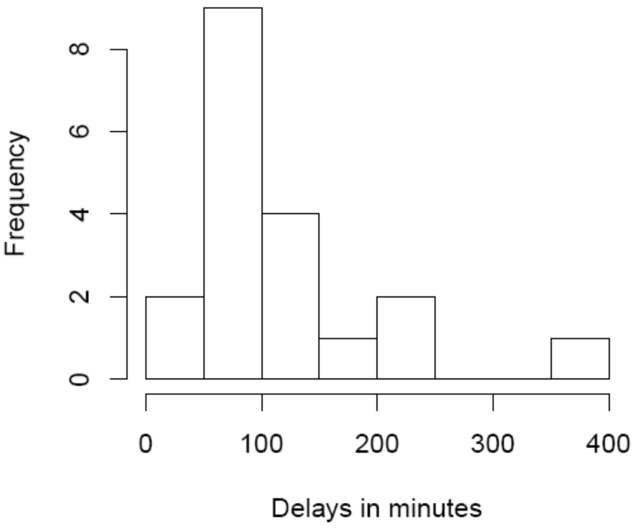
$$p_0, p_1 \geq 0$$

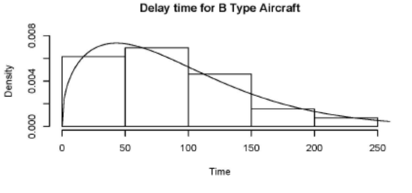
$$p_0 | data \sim Be(14, 23)$$

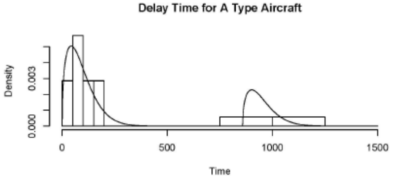
$$F_{d_B} \sim Wei(\theta = 0, \alpha, \beta)$$

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

$$f(x \mid \theta, \alpha, \beta) = \alpha \frac{(x - \theta)^{\alpha - 1}}{\beta^{\alpha}} \; \exp(-((x - \theta)/\beta)^{\alpha})$$







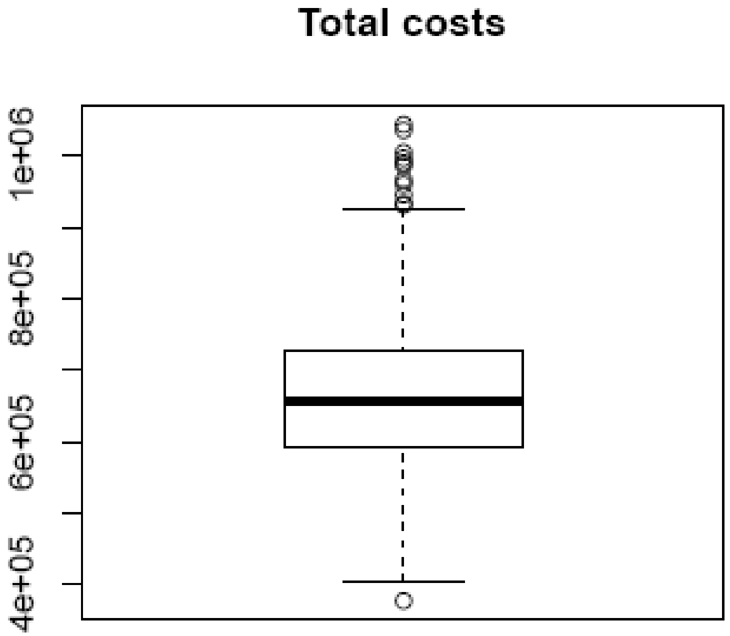
An example: Unintended slide deployment

- Costs in relation with delays

	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)

An example: Unintended slide deployment

- Annual costs due to incidents



An example from aviation operations: Risk management

- Countermeasures
  - Change procedure (to ‘eliminate’ interruptions and mitigate errors, pratically no cost)
  - Training course to key personnel (to mitigate errors and noncompliances, practically no cost)
  - Awareness campaign to key personnel through newsletters, etc… (same objective, cost 6000 euros)
  - Ligt and sound warning device at each door (to mitigate errors, interruptions andnoncompliances, cost 2500 euros per door) (or only Bf)
  - Visual reminders at each door (to mitigate errors adn noncompliances, cost 120 euros per door) (or only Bf)
- Note that, essentially, we only affect incident likelihood, but not incident severity

An example from aviation operations: Risk management

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

Expected cost
NPV

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

Conclusions

- Procedure revised+ awareness campaign.
- Communication far from simple….
- But results (4 vs 18) support management performed

Other examples

- **Best adaptation/mitigation in presence of extreme weather events (floods and droughts) in Jiquilisco (El Salvador**)
- Runway excursions
- Fuel for holding
- **State aviation safety plan**
- Fraud prevention in metro
- Protection against natural hazards in critical infrastructures