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ComplexityCost

What cost resilience?

Funded by:

ComplexityCost in a nutshell

Main objetives:

- *Better understand the Air Traffic performance trade-offs using a complex-networks approach.*
- *Consider different stakeholders and investment mechanisms for affording network resilience and robustness. Explore a variety of disruptions and its (knock-on) effects on the network.*
- *Define new performance metrics: Assign monetary cost and cost efficient metrics when possible. Passenger and flight centred metrics.*

And all of this in the context of uncertainty…

Resilience Engineering

- Focusing on “resilience engineering” for ATM, Hollnagel (2006) “safety-based design of socio-technical systems"

Capacity	Key feature	Key association(s)	Key phase
absorptive	network can withstand disruption	robustness, reliability	strategic
adaptive	flows through the network can be reaccommodated	reliability; often incorporates learning	strategic and/or tactical
recovery (or restorative)	recovery enabled within time and cost constraints	focuses on dynamics, amenable to analytical treatment	tactical

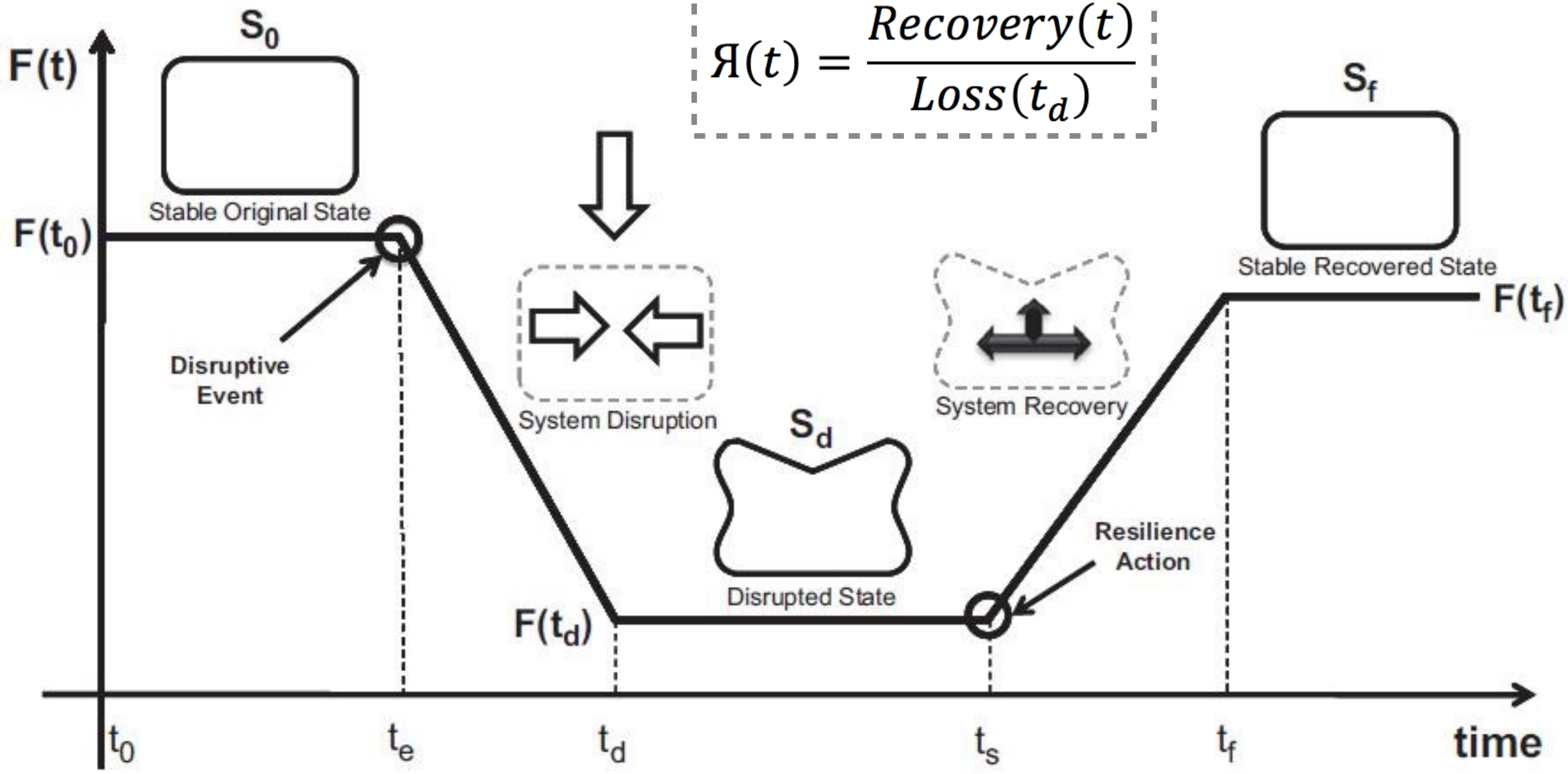
sources:

R. Francis and B. Bekara, “A metric and frameworks for resilience analysis of engineered and infrastructure systems”, Reliability Engineering and System Safety, 121 (2014), 90–103, 2013

M. Turnquist and E. Vugrin, “Design for resilience in infrastructure distribution networks”, Environmentalist, 33(1), 104–120, 2013.

Resilience metric

$$\text{Я}(t) = \frac{Recovery(t)}{Loss(t_d)}$$

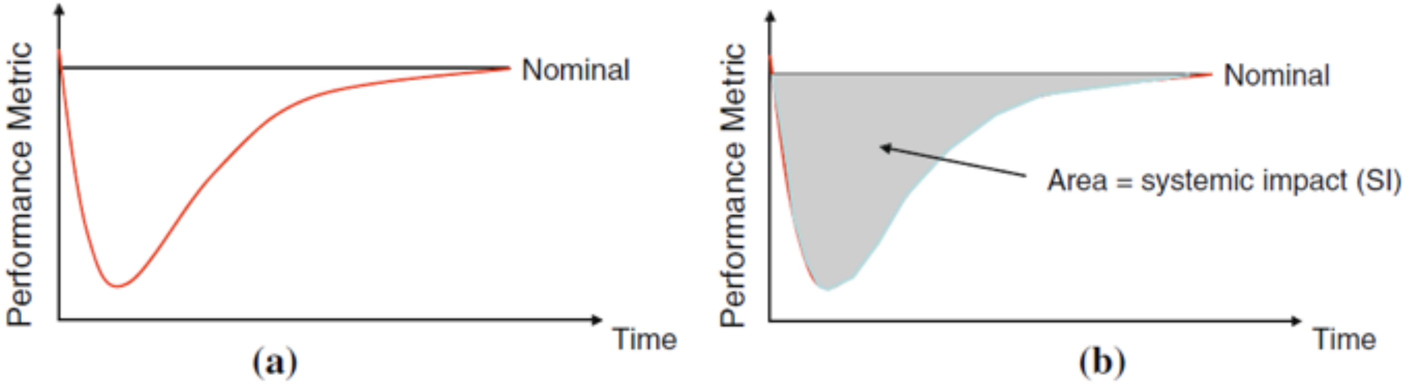


adapted from:

D. Henry and J.E. Ramirez-Marquez, “Generic metrics and quantitative approaches for system resilience as a function of time”, Reliability Engineering & System Safety, 99, 114–122, 2012.

Resilience metric

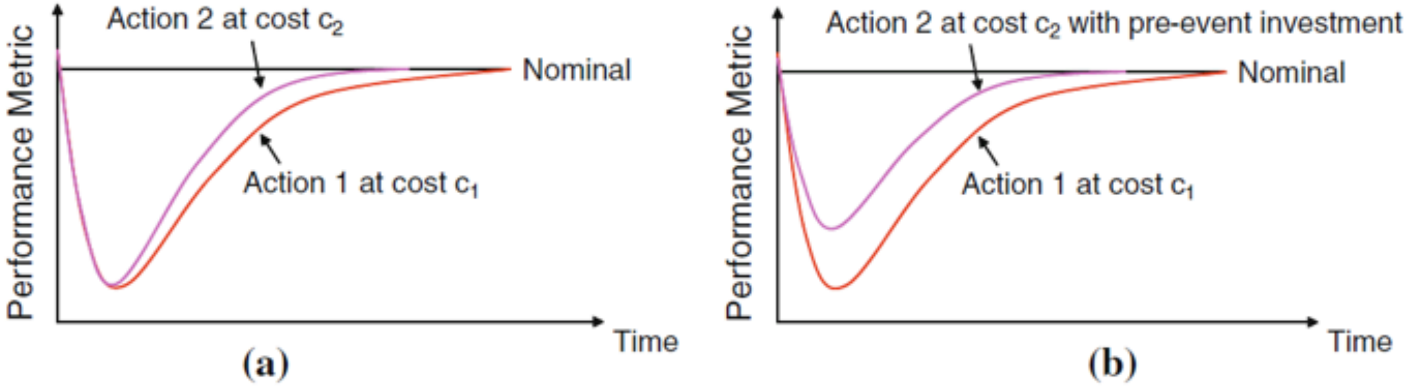
1



(a)

(b)

2



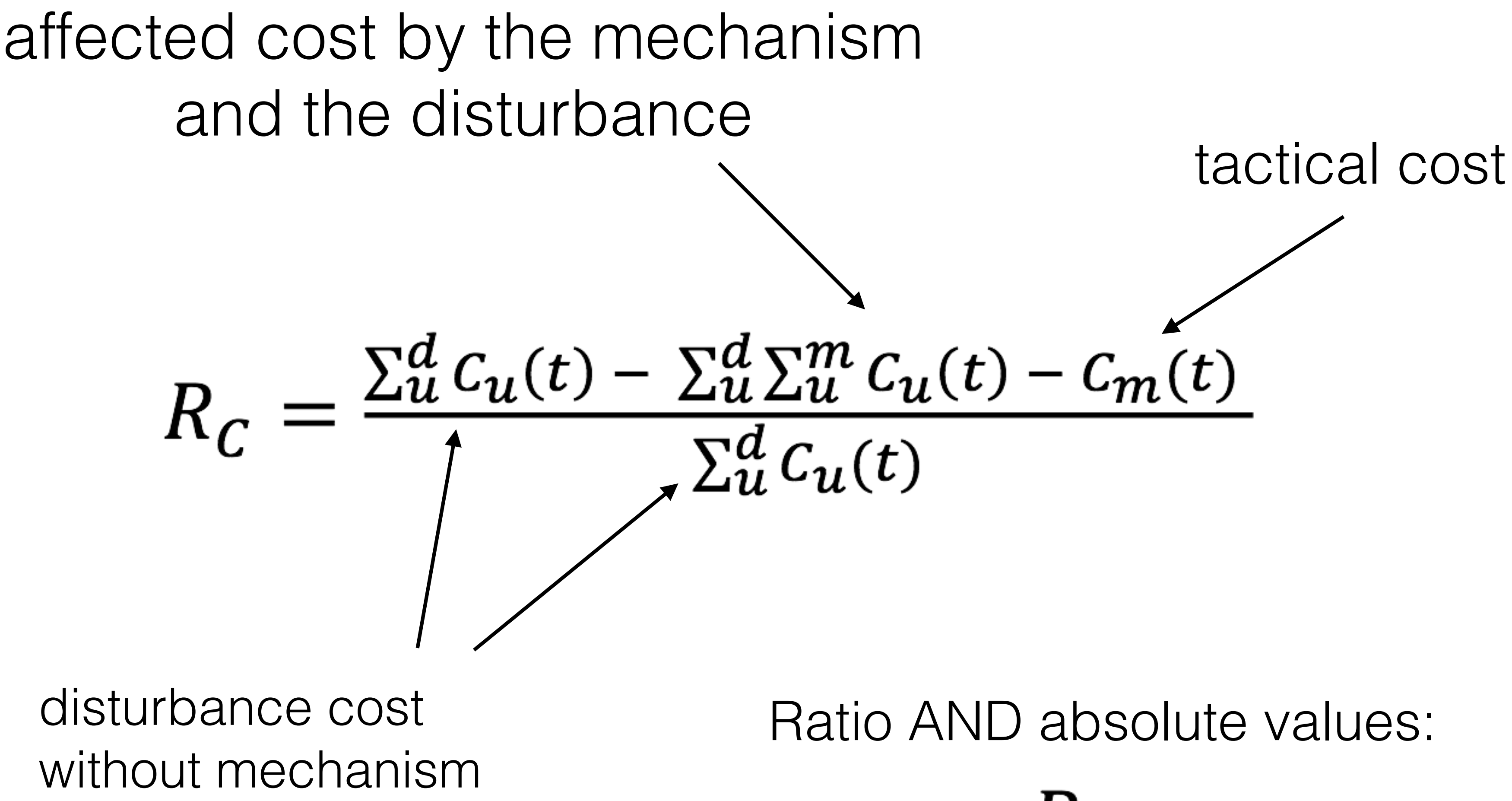
(a)

(b)

$$R = \frac{\int_{t_0}^{t_0+t_h} Q(t)\mathrm{d}t}{t_h}$$

Q(t) = Quality of service, usually a weighted average over a set of metrics. Not in ComplexityCost

Cost Resilience metric



affected cost by the mechanism
and the disturbance

tactical cost

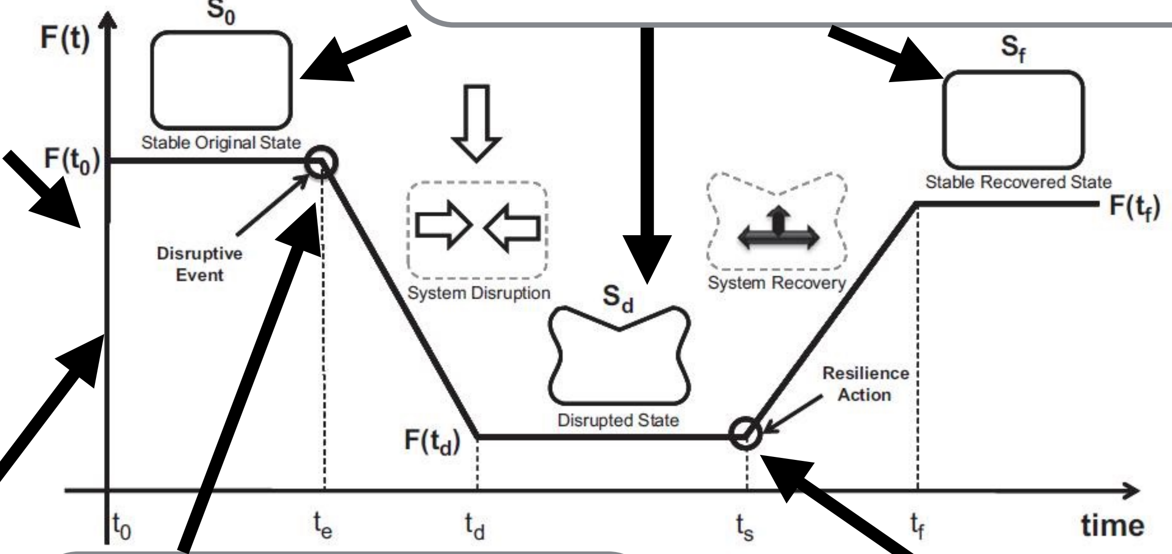
$$R_C = \frac{\sum_u^d c_u(t) - \sum_u^d \sum_u^m c_u(t) - c_m(t)}{\sum_u^d c_u(t)}$$

disturbance cost
without mechanism

Ratio AND absolute values:

R_C , n

ComplexityCost elements



ComplexityCost model: stochastic, event-driven network model

Passenger- and flight- centred metrics!

Cost performance!!

Study of disruptions (e.g. likelihood, intensity, …) analysing different data sources (e.g. CODA, METAR …)

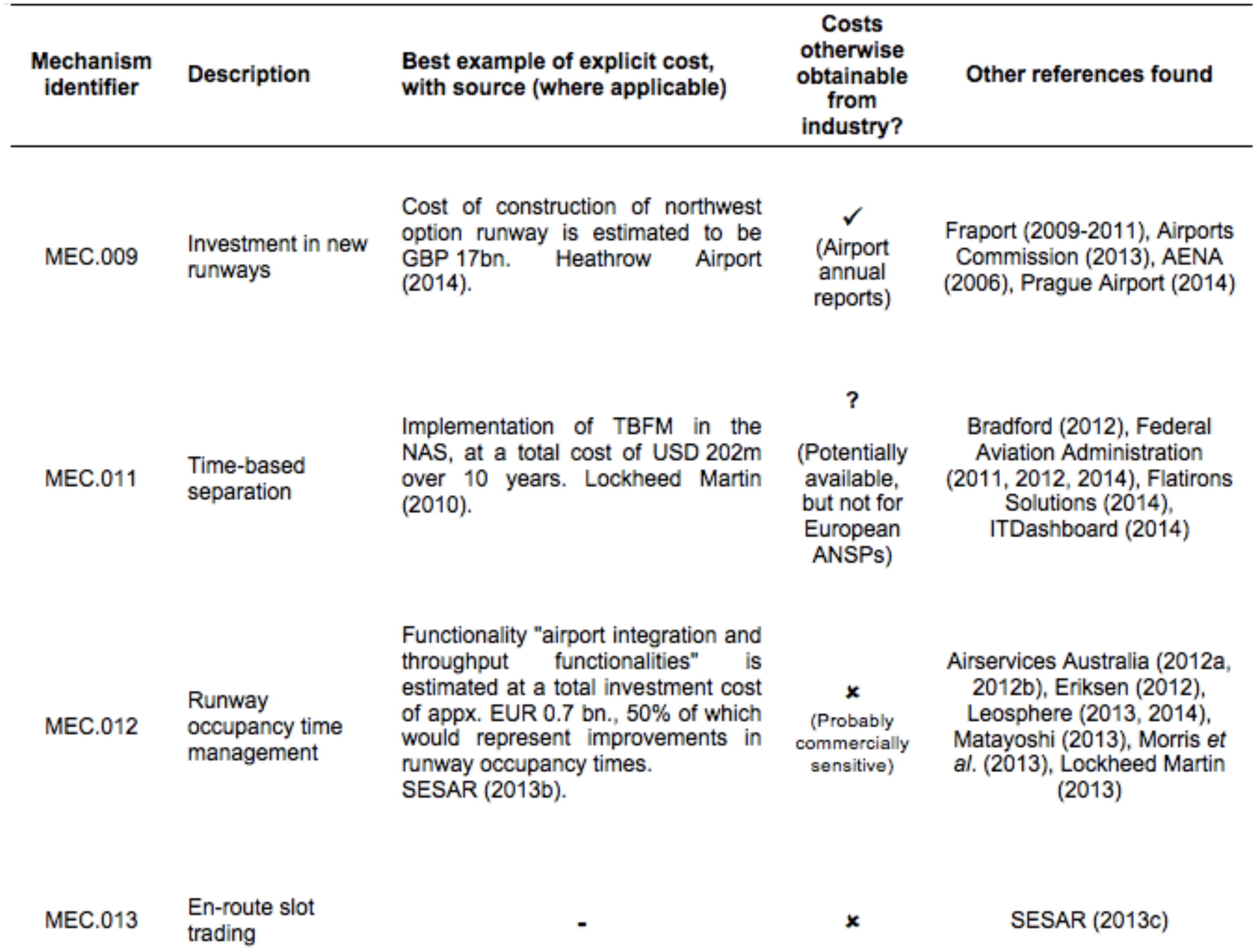
Study of mechanisms: feasibility, stakeholders uptake and categorisation

Mechanisms

Basic criteria considered to select the investment mechanisms

- Different types of mechanisms: basic (e.g. airline adding schedule to its buffer), advanced (e.g. User Driven Prioritisation Process)
- Cross-section of procedural, regulatory and technological types of change; addressing different flight phases
- Well known costs or amenable to reasonable estimation for their implementation (strategic) and operational (tactical)
- Modelled through different stakeholders uptake based on Rogers' (1983) Gaussian uptake distribution for innovation adoption lifecycles: 'early adopters', 'early majority' and 'late majority'

Mechanisms example



Mechanism identifier	Description	Best example of explicit cost, with source (where applicable)	Costs otherwise obtainable from industry?	Other references found
MEC.009	Investment in new runways	Cost of construction of northwest option runway is estimated to be GBP 17bn. Heathrow Airport (2014).	✓ (Airport annual reports)	Fraport (2009-2011), Airports Commission (2013), AENA (2006), Prague Airport (2014)
MEC.011	Time-based separation	Implementation of TBFM in the NAS, at a total cost of USD 202m over 10 years. Lockheed Martin (2010).	? (Potentially available, but not for European ANSPs)	Bradford (2012), Federal Aviation Administration (2011, 2012, 2014), Flatirons Solutions (2014), ITDashboard (2014)
MEC.012	Runway occupancy time management	Functionality "airport integration and throughput functionalities" is estimated at a total investment cost of appx. EUR 0.7 bn., 50% of which would represent improvements in runway occupancy times. SESAR (2013b).	✗ (Probably commercially sensitive)	Airservices Australia (2012a, 2012b), Eriksen (2012), Leosphere (2013, 2014), Matayoshi (2013), Morris *et al.* (2013), Lockheed Martin (2013)
MEC.013	En-route slot trading	-	✗	SESAR (2013c)

Disturbances

Type:

- Weather
- Ash plumes
- ATFM capacity restriction (non-weather)
- Strike actions
- Technical failures
- Passenger disruptions
- Military exercises

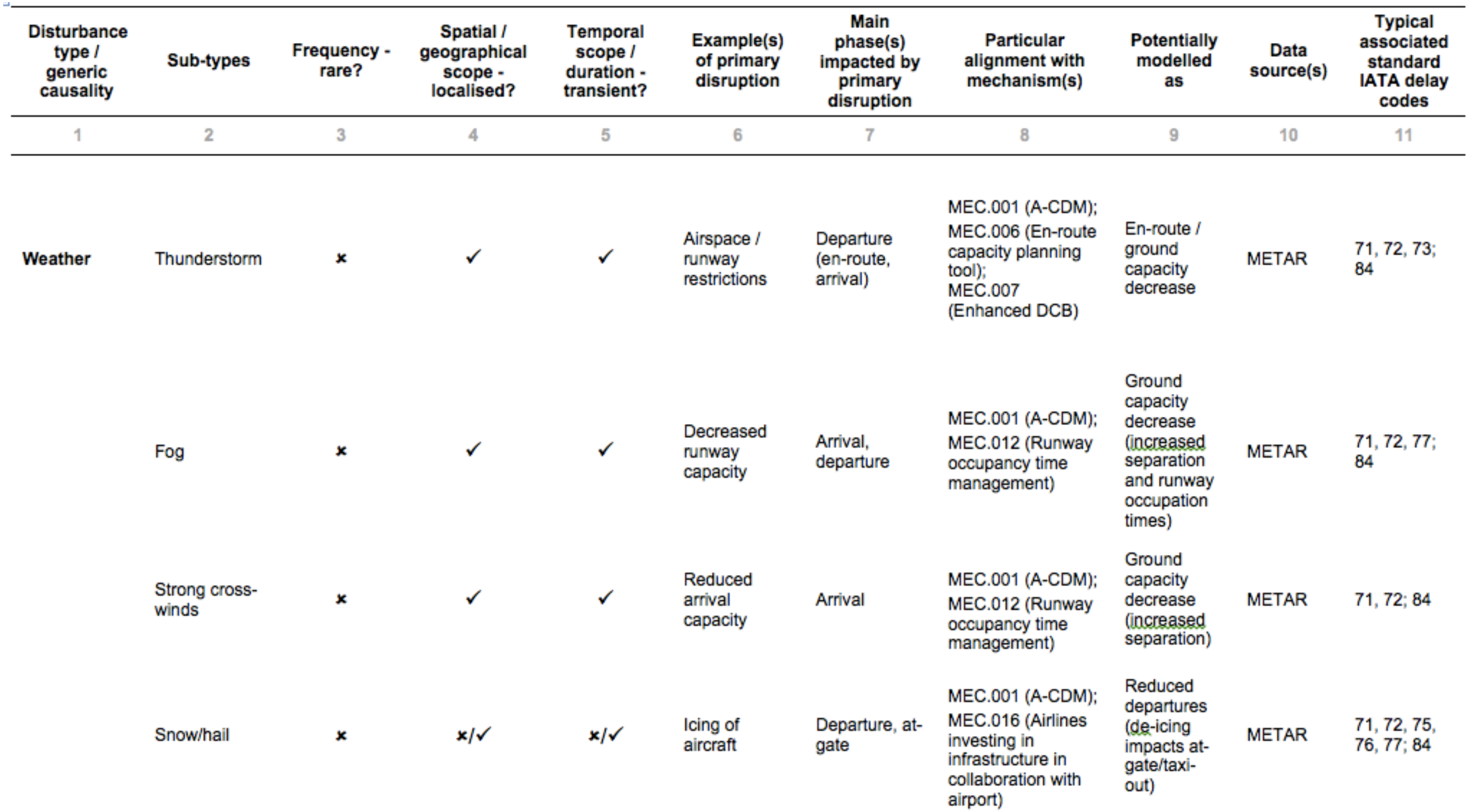
Scope:

- Localisation
- Duration
- Intensity
- Likelihood

Data availability:

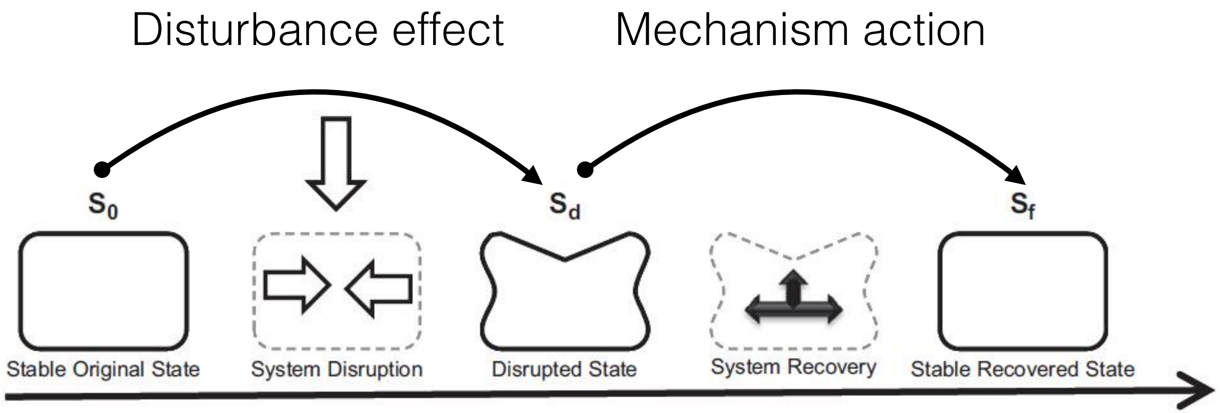
- CODA
- NOP
- METAR
- Other / Analysis

Disturbances example



Disturbance type / generic causality	Sub-types	Frequency - rare?	Spatial / geographical scope - localised?	Temporal scope / duration - transient?	Example(s) of primary disruption	Main phase(s) impacted by primary disruption	Particular alignment with mechanism(s)	Potentially modelled as	Data source(s)	Typical associated standard IATA delay codes
1	2	3	4	5	6	7	8	9	10	11
Weather	Thunderstorm	✗	✓	✓	Airspace / runway restrictions	Departure (en-route, arrival)	MEC.001 (A-CDM); MEC.006 (En-route capacity planning tool); MEC.007 (Enhanced DCB)	En-route / ground capacity decrease	METAR	71, 72, 73; 84
	Fog	✗	✓	✓	Decreased runway capacity	Arrival, departure	MEC.001 (A-CDM); MEC.012 (Runway occupancy time management)	Ground capacity decrease (increased separation and runway occupation times)	METAR	71, 72, 77; 84
	Strong cross-winds	✗	✓	✓	Reduced arrival capacity	Arrival	MEC.001 (A-CDM); MEC.012 (Runway occupancy time management)	Ground capacity decrease (increased separation)	METAR	71, 72; 84
	Snow/hail	✗	✗/✓	✗/✓	Icing of aircraft	Departure, at-gate	MEC.001 (A-CDM); MEC.016 (Airlines investing in infrastructure in collaboration with airport)	Reduced departures (de-icing impacts at-gate/taxi-out)	METAR	71, 72, 75, 76, 77; 84

ComplexityCost model



ComplexityCost model

ComplexityCost model

Modelling

- Stochastic, layered network with interacting elements and feedback loops
- Event driven simulation, parallel event processing, optimised stacks
- Soft-computing architecture
- Stochastic elements include systemic disturbance and specific modelled disturbance
- Cost allocation for passengers and airlines

Data:

- Traffic from busy (unexceptional) September 2014 traffic day as baseline
- 200 airports in the ECAC area + 50 beyond
- DDR2 for flight, capacity and airspace data
- Passenger allocation algorithms based on previous work with IATA data (+ #pax) and GDS

Cost Resilience example

But first, let’s be honest and allow me to cheat a bit…

Cost Resilience example

Using **POEM**’s model (base for ComplexityCost model)…

- 199 ECAC airports + 50 beyond region (busy day in September 2010)
- Passenger connectives and airline delay costs explicitly modelled
- Airline decision making mechanism applied to decide how long to wait for connecting passengers

… to compute **ComplexityCost**’s “Cost Resilience metric.”

Cost Resilience example

	Total delay cost		
	without mechanism	**with mechanism**	
Nominal Delays	€16.11 m	€14.95 m	7.2%
Increased Delays	€17.08 m	€16.02 m	6.2%
	5.8%	6.8%	**Cost Resilience Rc** (with n=29.555)

- Up to € 1.16 m can be invested (benefit of mechanism in nominal day) and ensure a positive resilience in both scenarios
- A monthly cost of up to €1.5m would be worthwhile for top ten carriers

Thank you for your attention

Have questions? ask now or later:
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