What cost resilience?

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Overview

• Background and objectives

• ComplexityCosts model
  – Overview
  – Stakeholder uptake
  – Mechanisms
  – Disturbance
  – Cost allocation

• Resilience
  – Metric
  – Example

• Next steps
Background and objectives
Background and objectives

ATM Network

Mechanism(s)

Indicators

Stakeholders

Airlines
ANSPs
Airports

...
Background and objectives

Mechanisms

Resilience

Disruptive event

Resilience action

F(t)

S₀

Sₐ

Sₜ

S₅

F(tₖ)

F(t₀)

Time
tₑ
tₕ
tₛ
tₜ
Background and objectives

- Reflect operational realities for investment mechanisms
- Consider disturbance as event capable of causing the system to change its specified state, as determined by one or more metrics
Complexity cost model
- Overview
Overview

• Modelling
  – Stochastic, layered network with interacting elements and feedback loops
  – Stochastic elements will 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
  – Other data required has been identified
Complexity cost model
- Stakeholder uptake
Stakeholder uptake

- Differentiated degree of adoption of mechanism for user groups
- Based on stakeholder characteristics and mechanism characteristics
  - ANSPs: size, traffic density, regulatory
  - Airlines: business model
  - Airports: ownership, size, number of runways, slot coordination status, hub status
Complexity cost model
- Mechanisms
Mechanisms

- Basic criteria considered to select the investment mechanisms
  - Different types of mechanisms: basic, advanced
  - 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
## Mechanisms

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Summary description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advanced</td>
<td>SESAR Essential Operational Changes and sub-components thereof</td>
<td>Airport collaborative decision making (A-CDM)</td>
</tr>
<tr>
<td>Basic</td>
<td>Non-advanced, does not centrally involve implementing new technologies/tools.</td>
<td>Airline adding buffer to its schedule</td>
</tr>
<tr>
<td><strong>Disturbance focus</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mitigation</td>
<td>Primarily aimed at mitigating the impacts of disturbance.</td>
<td>Spare aircraft crews with dynamic rostering.</td>
</tr>
<tr>
<td>Nominal</td>
<td>Primarily aimed at improving the nominal functioning of the system</td>
<td>Additional runway capacity</td>
</tr>
</tbody>
</table>
Mechanisms

Deployment Baseline

2014

Pilot Common Project

ConOps 1

2018

2025

ConOps 2/3

2025+

SESAR Master Plan

Fourth SESAR Innovation Days
UPM, Madrid, 25 - 27 NOV 2014
Complexity cost model
- Disturbances
Disturbances

- Disturbances described by
  - Type
  - Frequency of occurrence
  - Localisation
  - Duration
  - Intensity

Scope

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

- CODA
- NOP
- METAR
- Other / Analysis
Complexity cost model
- Cost allocation
Cost allocation

- Airline costs for delay
  - Strategic (airline buffer)
  - Tactical (day of operations)
  - Reactionary delays will also be assessed

- Cost updated to 2014 values

- ‘High’, ‘base’ and ‘low’ costs scenarios considered

- Fleet
- Fuel (and carbon)
- Crew
- Maintenance
- Passenger costs
Background and objectives

Mechanism(s)

ATM Network

Indicators

Stakeholders

Airlines
ANSPs
Airports

...
Resilience
## Resilience

### Major definitions

<table>
<thead>
<tr>
<th>Terminology</th>
<th>Introduction</th>
<th>Field</th>
<th>State(s)</th>
<th>Key feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering resilience</td>
<td>Hoffman (1948)</td>
<td>material testing</td>
<td>one stable</td>
<td>inherent ability of the system to return to its original state</td>
</tr>
<tr>
<td>Ecological resilience</td>
<td>Holling (1973)</td>
<td>ecology</td>
<td>multiple</td>
<td>ability of the system to absorb disturbance</td>
</tr>
</tbody>
</table>
Resilience

- Major definitions

- Resilience

\[ F(t) \]

\[ F(t_0) \]

\[ S_0 \]

\[ S_a \]

\[ S_d \]

\[ S_t \]

\[ t_e \]  Disruptive event

\[ t_d \]  Resilience action

\[ t_s \]  

\[ t_f \]  

\[ F(t_f) \]
## Resilience

### Capacities

<table>
<thead>
<tr>
<th>Capacity</th>
<th>Key feature</th>
<th>Key association(s)</th>
<th>ATM focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absorptive</td>
<td>network can withstand disruption</td>
<td>Robustness; little or no change may be apparent</td>
<td>strategic</td>
</tr>
<tr>
<td>Adaptive</td>
<td>flows through the network can be accommodated</td>
<td>change is apparent; often incorporates learning</td>
<td>strategic and/or tactical</td>
</tr>
<tr>
<td>Restorative</td>
<td>Recovery enabled within time and cost constraints</td>
<td>May focus on dynamics/targets; amenable to analytical treatments</td>
<td>tactical</td>
</tr>
</tbody>
</table>
Resilience
- Metric
Metric

\[ \mathcal{R}(t) = \frac{\text{Recovery}(t)}{\text{Loss}(t_d)} \]
Metric

\[ R = \int_{t_0}^{t_0+\tau_h} Q(t) dt \]
Metric

• ATM context
  – Metric characteristics
    • Intelligible
    • Pertinent
    • Stable
  – Difficulty to establish the time over which a recovery occurs
    • Use one operational day in European airspace as the boundary conditions
  – Cost based metric
  – Return investment value
    • Ratio and absolute value relevant
    – Tactical costs of running the mechanisms considered

\[ \mathcal{R} = \frac{50}{100} = 0.5 \]
\[ \mathcal{R} = \frac{50k}{100k} = 0.5 \]
Metric

- ATM metric

\[ R_C = \frac{\sum_u C_u(t)}{\sum_u C_u(t)} - \frac{\sum_u \sum_u C_u(t)}{\sum_u C_u(t)} - C_m(t) \]

\[ R_C \leq 1 \]
Resilience
- Example – Applying a mechanism
Applying a mechanism

Σ = +20  (at this planning stage)
Applying a mechanism

\[ R_C = 0 \]

\[ \Sigma = +30 \]

\[ \Sigma^d_u \Sigma^m_u \]
Applying a mechanism

- Retrospective example
  - 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 (t>=0) for connecting passengers
## Applying a mechanism

<table>
<thead>
<tr>
<th>Scenario modelled</th>
<th>Total network delay cost</th>
<th>Cost resilience ($R_c$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>without mechanism</td>
<td>with mechanism</td>
</tr>
<tr>
<td>Nominal delays</td>
<td>€ 16.11 m</td>
<td>€ 14.95 m*</td>
</tr>
<tr>
<td>Increased delays</td>
<td>€ 17.08 m</td>
<td>€ 16.02 m*</td>
</tr>
</tbody>
</table>

* $p<0.01$ for cost reduction relative to no mechanism

$n=29,555$

- Average saving for a nominal day is 39 € per flight
- € 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
Next steps
Next steps

• Model the different monetised mechanisms
  – Mechanisms focus between SESAR Deployment Baseline and ConOps Step 1
• Define passenger and flight centric metrics to compare mechanisms
• Further develop event-driven model to assess disruptions and their impact
• Improve the understanding of complex interdependencies
• Further define a framework to compare advanced and basic investment mechanisms to develop new cost-benefit analysis
Thank you