Modelling strategic trade-offs - insights into the SESAR ‘Vista’ project
Cook, A.J., Delgado, L. and Gurtner, G.

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Modelling strategic trade-offs
Insights into the SESAR ‘Vista’ project

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University of Westminster, London

AGIFORS 57th Annual Symposium
London, 02-06 October 2017
Overview of presentation

• Objectives of Vista

• Overview of the model
  • principles and construction

  • The tactical layer
    • most mature – presented elsewhere
  • The pre-tactical layer
    • key bridge
  • The strategic layer
    • focus today

• Trade-off analysis

• Next steps & discussion
  • not conclusions, rather an open dialogue
Objectives of Vista
Objectives of Vista

- Current
- 2035
- 2050

KPIs established for 2015 (all in SES PS, RP2)
Objectives of Vista

- Market/business forces working with/against regulation – unintended consequences?
  - cheaper to cancel a flight? (Reg. 261)
  - delay recovery v. emissions impact? (ETS; Directive 2008/101)
  - ANSP delay levels driven too low? (SES PS; Reg. 549/2004)

- Impact metrics
  - classical (e.g. average delay) & complexity (e.g. community detection)
  - monetised (e.g. cost of delay) and quasi-cost ($NO_x$, $\sigma_{arr}^2$)

WP3 Market forces          WP4 Evaluation framework          WP5 Impact trade-offs

Business forces
Regulatory forces

Passengers
Airlines
ANSPs
Airports
Environment

Scenarios

WP6 Stakeholder assessment & dissemination

Full cost
Quasi-cost

Metrics
Overview of the model
Overview of the model

- The forces/factors considered are subdivided into two main categories:
  - **Business factors (37)**: cost of commodities, services and technologies, volume of traffic, etc. => demand and supply
  - **Regulatory factors (22)**: from EC or other bodies, e.g. ICAO, => ‘rules of the game’; some of these are enablers of the business factors

- 85 references consulted

- Further split into ‘background’ and ‘foreground’ factors:
  - **Background**
    - often drive fundamental system evolution
    - e.g. economic development of the EU-EFTA zone (high/medium/low)
  - **Foreground**
    - factors whose impact are to be studied explicitly, in more detail
    - e.g. cost of fuel
Overview of the model

- Three-layer/stage:
  - Macro-economic model for demand & capacity
  - Generation of flight and passengers itineraries
  - Mobility model

- Quantitative results
  - Level of detail adapted for phases

- Individual flights and pax itineraries generated for 2035 and 2050
  - Number of executions required
Overview of the model
## Overview of the model

### Sublayer & components

<table>
<thead>
<tr>
<th>Factors</th>
<th>Strategic layer</th>
<th>Pre-tactical layer</th>
<th>Tactical layer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Economic model</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Airport</td>
<td>ANSP</td>
<td>Airline</td>
</tr>
<tr>
<td>ROR1</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>ROR3</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>ROR4</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROR9</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>RAD1</td>
<td>✓</td>
<td>✓</td>
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</tr>
<tr>
<td>RAD2</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>RAA1</td>
<td>✓</td>
<td>✓</td>
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</table>

### Background scenario definition

<table>
<thead>
<tr>
<th>Period</th>
<th>Name</th>
<th>Description</th>
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<tbody>
<tr>
<td>Current</td>
<td>Current</td>
<td>Default</td>
</tr>
<tr>
<td>2035</td>
<td>L35</td>
<td>Low economic Low techno</td>
</tr>
<tr>
<td></td>
<td>M35</td>
<td>High economic Low techno</td>
</tr>
<tr>
<td></td>
<td>H35</td>
<td>High economic High techno</td>
</tr>
<tr>
<td>2050</td>
<td>L50</td>
<td><em>(As per 2035)</em></td>
</tr>
<tr>
<td></td>
<td>M50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H50</td>
<td></td>
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</table>
### Overview of the model

#### Foreground factors

<table>
<thead>
<tr>
<th>ID</th>
<th>Business factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>BTS5</td>
<td>4D Trajectory Management</td>
</tr>
<tr>
<td>BTS9</td>
<td>Traffic synchronisation</td>
</tr>
<tr>
<td>BTO4</td>
<td>Passenger reaccommodation tools</td>
</tr>
<tr>
<td>BEO1</td>
<td>Fuel prices</td>
</tr>
<tr>
<td>BEO2</td>
<td>Airspace charges</td>
</tr>
<tr>
<td>BEO3</td>
<td>Airline business models (output)</td>
</tr>
<tr>
<td>BEO4</td>
<td>Smart, integrated ticketing</td>
</tr>
</tbody>
</table>

#### Regulatory factors

<table>
<thead>
<tr>
<th>ID</th>
<th>Regulatory factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROR1</td>
<td>Passenger provision schemes</td>
</tr>
<tr>
<td>ROR3</td>
<td>Emission schemes</td>
</tr>
<tr>
<td>ROR4</td>
<td>Noise pollution (implicit)</td>
</tr>
<tr>
<td>RAD1</td>
<td>Airport slots</td>
</tr>
<tr>
<td>RAD2</td>
<td>Regional airport development</td>
</tr>
<tr>
<td>RAA1</td>
<td>Airport access</td>
</tr>
<tr>
<td>ROR9</td>
<td>Operation of air services</td>
</tr>
</tbody>
</table>

#### Foreground groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EM</td>
<td>Environmental mitigation policies</td>
</tr>
<tr>
<td>PF</td>
<td>Passenger focus</td>
</tr>
<tr>
<td>RI</td>
<td>Regional infrastructures</td>
</tr>
<tr>
<td>SES</td>
<td>Single European Sky</td>
</tr>
</tbody>
</table>
Overview of the model

**JIRA**

What it is: Project-tracking software
Why we’re using it: Shared task definition environment
Scrumb/agile methodology
Seamless integration with Confluence

**Python**

What it is: High-level (object-oriented) language
Why we’re using it: Open source
Extensive support libraries
Large on-line community

**GitHub**

What it is: Software development platform /repository
Why we’re using it: Allows collaborative software development
Good re. branches & forks: parallel dvp’ment
Common store / back-up of source code

**Amazon DynamoDB**

What it is: Partially NoSQL*, cloud-hosted database
Why we’re using it: Partial modification ease (*lack of dependencies)
Cloud service with backed-up data
Resources allocated automatically
The tactical layer
What is Mercury?

- Framework for EU mobility performance and assessment
- Flexible to implement almost any *scenario* (event-driven)
- Focus on explicit passenger itineraries (3.8m pax), c.f. flights
- Produces a wide range of metrics, not only delays
- Developed and tested over 7 years of research under several initiatives (SESAR*, H2020) with a range of stakeholders

- Mesoscopic (D2D) approach; *stochastic modelling*
- Airline decisions based on *cost models* (e.g. Reg 261) and *rules* (current, or ‘what-if’)
- Includes disruptions, cancellations, re-accommodation and compensation costs
- Incorporates ATM demand/capacity balance model (ATFM slots)

*SESAR Outstanding Project award, 2014 (POEM)*

http://innaxis.org/mercury/portfolio/
The tactical layer

- POEM, ‘A1’ scenario: cost-minimising aircraft wait rules, c.f. baseline

Smaller airports (more) implicated in delay propagation
Back-propagation important in persistence of network delay
  - CDG, MAD, FRA, LHR, ZRH, MUC: all > 100 hours (baseline day)
Propagation contained within smaller airport communities
  - ... but these communities more susceptible to such propagation
  - largest persistent airports: Athens, Barcelona & Istanbul Atatürk

All scenarios: no statistically signif. changes in current flight-centric metrics!

- €39 avg. cost / flight  (x27k > €1m)
- 9.8 mins avg. arrival-delayed pax
- 2% reactionary delay
The tactical layer

Door-to-door context and 2050 (also courtesy DATASET2050)

Airport access: data-driven stochastic processes

Pax profiles linked with itineraries

Confidential access to airport process times
The pre-tactical layer

E.g. (near-final) capacities and demand
The pre-tactical layer

- Flight schedules
- Passenger flows
- Flight plans
- ATFM delays
- Passenger itineraries

IATA, GDS; MCTs; traffic (high effort)
The strategic layer

E.g. regulations, technologies, forecasts
The strategic layer

• Strategic layer – economic model (takes into account macro-economic factors)

• Desired outputs:
  • main flows in Europe
  • market share of different airline types
  • capacities of ANSPs and airports
  • average prices for itineraries

• Need to take into account:
  • main changes in demand (volume, pax heterogeneity)
  • major business model differences and changes:
    • point-to-point v. hub-based (airlines)
    • competition v. cooperation (ANSP)
    • privatisation v. nationalisation (ANSP and airports)
  • capacity restrictions (congestion at airports; ATCO resource constraints)
  • major changes of commodity prices (e.g. fuel, airport and airspace charges)
The strategic layer

- Turn-based, multi-agent model
- Currently features three types of agents:
  - airport (one agent per airport)
  - airline (one agent per airline)
  - passengers (one agent per OD pair, including all possible itineraries)
  - ANSPs (soon: able to adjust prices after several turns -> AO choice; Reg. 391/2013)

- Each agent has its own objective, with a specific cost function:

AO flight cost function
- fuel
- airport charges
- ATC charges
- other BHDOCs
- delay costs

Pax utility function
- price of ticket
- income
- frequency of flights
- delay

Airport revenues and costs
- aeronautical charges
- operating cost of capacity
The strategic layer

Turns:

- **airlines**
  - estimate prices of each itinerary (based on past prices)
  - estimate delays at airports (based on past delays)
  - set operated capacity by airport pair (based on est. delays & prices)

- **airports**
  - estimate their traffic
  - decide whether to expand capacity* (based on expected traffic, & costs)

- **passengers** choose between itineraries for given OD pairs
- **selling price** of each itinerary is updated
  - based on balance between supply & demand

- **delays** are updated (based on ‘actual’ traffic)
- **airports and airlines** compute final profit

* availability lagged by several turns
The strategic layer

Simple scenarios to test / illustrate the model

Scenario:
shock (doubling) fuel price

-> costs on all OD pairs increase

‘mainline’, hub-based
‘low-cost’, P2P
The strategic layer

Simple scenarios to test / illustrate the model

- **Selling price**
  - Step 0 to 3: Mainline
  - Step 2 to 0: Mainline
  - Step 1 to 0: Mainline
  - Step 1 to 3: Low-cost
  - Step 2 to 3: Low-cost

- **Volume**
  - Step 0 to 10: Low-cost
  - Step 10 to 20: Low-cost
  - Step 20 to 30: Mainline

- 'Mainline', hub-based
- 'Low-cost', P2P
The strategic layer

Simple scenarios to test / illustrate the model

- 'mainline', hub-based
- 'low-cost', P2P

Profit

Market share

Step
The strategic layer

Calibration is carried out in several steps:

• **Direct calibration**
  - Extract values from historical data (including literature) and put them directly in the model (e.g. pax price elasticity)
  - Assign phenomenological relationships obtained otherwise (e.g. airline cost of delay)

• **Indirect calibration**
  - Supervised learning: a parameter is swept (in a smart way) in order for another one to reach a value extracted from data (e.g. cost of capital for airlines is calibrated to produce historical flows of pax between airports)
  - Reinforcement learning: agents modify their behaviour to be self-consistent across layers (e.g. cost of delay used to compute main flows should be the same as the actual tactical cost of delay)
The strategic layer

Rather more detailed examples to share with you, but too time consuming to include within whole overview

- local increase in demand
- increase in fuel price
- local capacity increase
Trade-off analysis
Trade-off analysis

Scenario

Factor 1
- Val1
- Val2
- Val3
- Val4

Factor 2
- Val1
- Val2
- Val3

Factor 3
- Val1
- Val2
- Val3

Factor 4
- Val1
- Val2
- Val3
- Val4

Model

Metric consolidation

KPIs Stakeholder 1
- KPI1
- KPI2
- KPI3
- KPI4

KPIs Stakeholder 2
- KPI1
- KPI2

KPIs Stakeholder 3
- KPI1
- KPI2

Trade-offs

AGIFORS 57th Annual Symposium, London, 02-06 October 2017
Trade-off analysis

- Box plots for m1-s1, m1-s2, m1-s3, and m2-s3
- Density plot with curves s1, s2, and s3
- Radar chart with m1, m2, m3, m4, m5, m6, m7, and m8
Thank you ...
... next steps & discussion
Next steps

- Dedicated Vista workshop, discussing stakeholder needs, hosted by Frequentis
  - 23 October, Vienna
  - airspace-research@westminster.ac.uk

- SESAR Innovation Days conference
  - full paper and presentation
  - 28-30 November, Belgrade
  - http://www.sesarju.eu/sesarinnovationdays

- Both free, but require registration
Discussion

- At this stage in the design process, we’d very much welcome your feedback
- Of course, we’re fully open to any questions, too
- For the airlines in particular:
  - Can you quantify the trade-offs between KPIs, such as OTP and market share?
  - For which trade-offs do you have least insight now, but the greatest need?
  - What is your strategic business scanning ‘horizon’ (2020? 2035?) – and why?
  - Do you carry out modelling similar to that of Vista?
  - What are the major benefits and shortcomings of Vista’s (holistic) approach?
  - What would be the key outputs of use to you, and is anything missing?
  - How do you calculate your cost functions (e.g. for a new aircraft – OEM data?) and production functions (e.g. for a new type of operation)?
Stand-bys
# Metrics

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Metrics</th>
<th>Stakeholder</th>
<th>Metrics</th>
</tr>
</thead>
</table>
| Passengers  | - Number / volume  
  - Delay (departure, arrival; reactionary)  
  - Gate-to-gate time  
  - Door-to-door time | Airlines | - Number / volume (flights, pax)  
  - Delay (departure, arrival; reactionary)  
  - Revenue and costs (incl. delay) | - Missed connections  
  - Hard / soft costs  
  - Value of time (utility) |
|             |         | ANSPs       | - Number / volume (flights)  
  - Delay (generated, mitigated) | - Gate-to-gate time (OTP)  
  - Missed connections  
  - Gate-to-gate time |
|             |         | Airports    | - Number / volume (flights, pax)  
  - Delay (departure, arrival; reactionary)  
  - Revenue and costs (incl. delay) | - Missed connections |
|             |         | Environment | - CO₂ | - NOₓ |
Trade-off example: LCC v. mainline

- steps 5-15: slowly increase demand on γ
- step 90: airport 3 increases its capacity
- step 170: increase of fuel price by 20%
## Trade-off analysis

<table>
<thead>
<tr>
<th>Approach</th>
<th>Key reference</th>
<th>Major advantage (new insights)</th>
<th>Greatest challenge</th>
<th>Alignment with model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pareto frontier</td>
<td>Pardalos <em>et al.</em> (2008)</td>
<td>Defines an essential notion for efficiency</td>
<td>Hard to compute in real-word examples, there may be no Pareto points at all</td>
<td>The model could be used as a parameter-metric function, exploration of parameter space could be done in parallel using the cloud-based infrastructure</td>
</tr>
<tr>
<td>Expected utility and prospect theory, Bayesian networks</td>
<td>Wakker <em>et al.</em> (2010)</td>
<td>Creates maps and identifies dependencies</td>
<td>Links and conditional dependencies are hard to determine</td>
<td>Aligns very well with soft computing methods, dependences can be explicitly computed within the model</td>
</tr>
<tr>
<td>Granger causality</td>
<td>Hoover (2001)</td>
<td>Discerns between correlation and causality</td>
<td>Needs large time series to work</td>
<td>Already proven in POEM model (Cook <em>et al.</em>, 2013)</td>
</tr>
<tr>
<td>Precursor-successor analysis</td>
<td>POEM model (Cook <em>et al.</em>, 2013)</td>
<td>Determines causes and effects systematically to create a knock-on effects tree</td>
<td>Hypothesis testing for the random tree generated could be an issue</td>
<td>Naturally intrinsic to the model, thanks to the event-driven paradigm</td>
</tr>
</tbody>
</table>

Key point of interest: tipping points (e.g. between emissions cost & delay recovery)