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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

Drs Andrew Cook, Luis Delgado & Gérald Gurtner
University of Westminster, London

AGIFORS 57th Annual Symposium
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Vista

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innaxis innovation for a complex world

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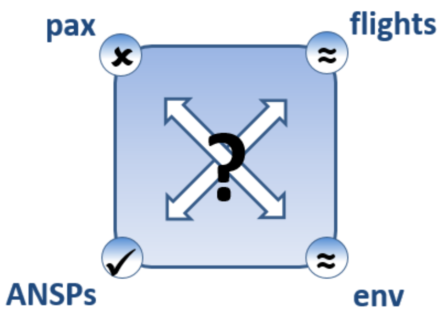
ICELANDAIR

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

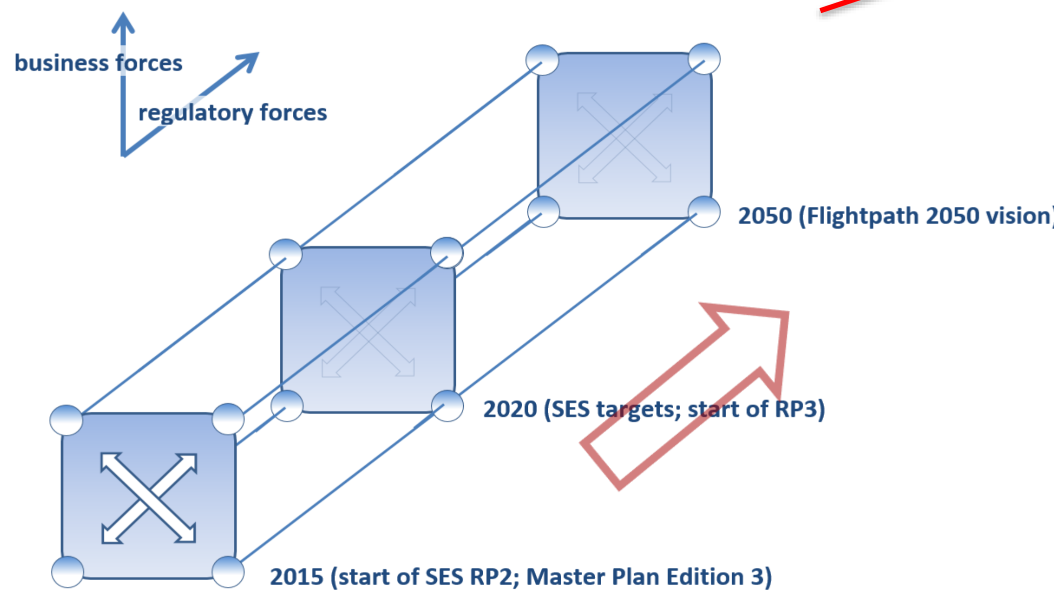


(+ airports)

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

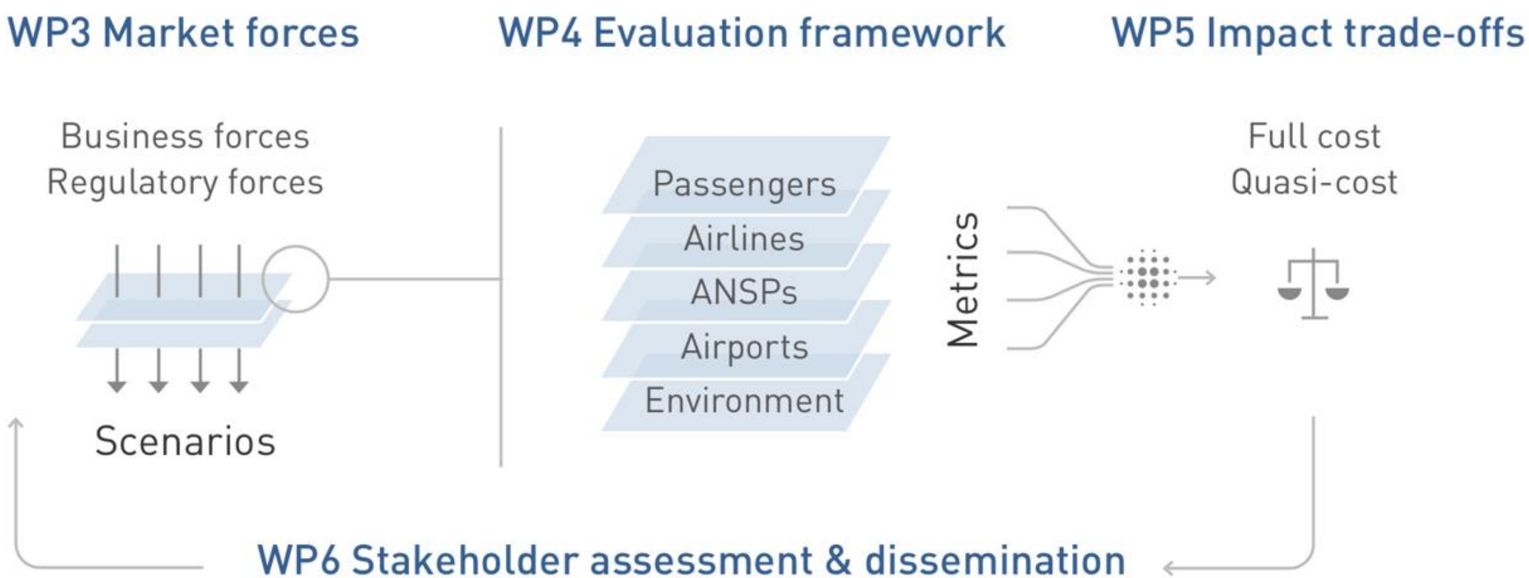
- Current
- 2035
- 2050

~~micro~~?



Objectives of Vista

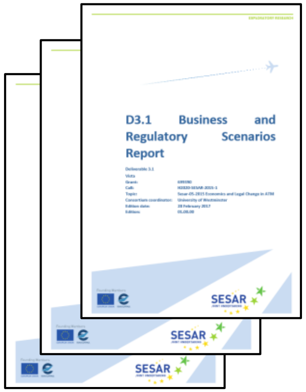
- Market/business forces working with/against regulation – unintended consequences?
  - cheaper to cancel a flight? (Reg. 261)
  - delay recovery *v.* emissions impact? (ETS; Directive 2008/101)
  - ANSP delay levels driven *too* low? (SES PS; Reg. 549/2004)
- Impact metrics
  - classical (e.g. average delay) & complexity (e.g. community detection)
  - monetised (e.g. cost of delay) and quasi-cost (NO_x, σ^2_{arr})



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

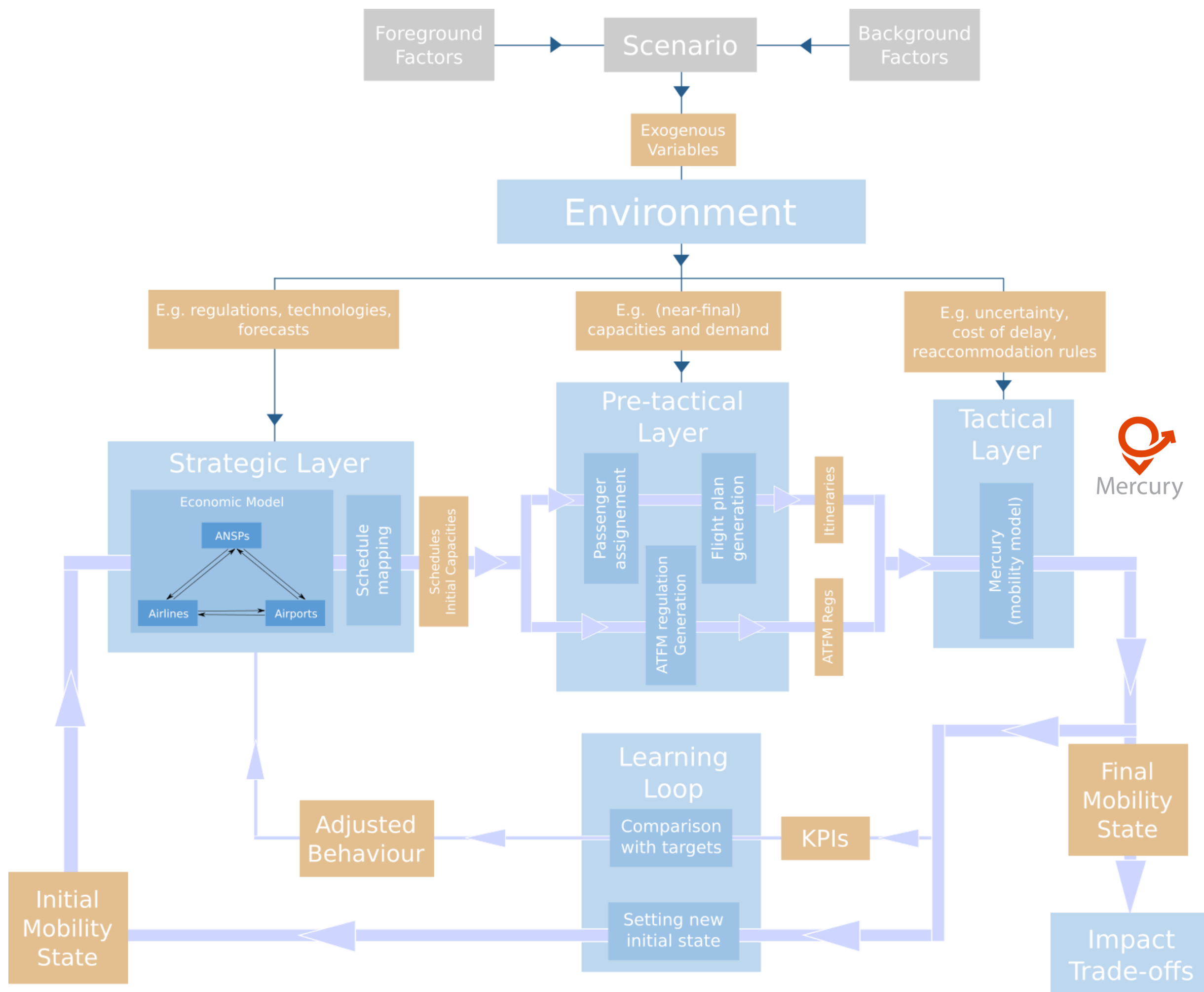
Overview of the model

- 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

Factors	Sublayer & components							
	Strategic layer					Pre-tactical layer		Tactical layer
	Economic model			Schedule mapping	Passenger assignment	Flight plan generation	ATFM reg. generation	Mercury
	Airport	ANSP	Airline					
ROR1			✓	✓	✓			✓
ROR3			✓					✓
ROR4	✓			✓			✓	✓
ROR9			✓	✓				
RAD1	✓		✓	✓				
RAD2	✓		✓	✓	✓			
RAA1	✓		✓	✓				

Background scenario definition

Period	Name		Description
Current	Current		Default
2035	L35	Low economic Low techno	**Economic growth slow** in Europe **Technological** & operational changes **not supported**
	M35	High economic Low techno	**Economic growth high** in Europe **Technological** & operational changes **not supported**
	H35	High economic High techno	**Economic growth high** in Europe **Technological** & operational changes **are supported**
2050	L50		(As per 2035)
	M50		
	H50		

Overview of the model

Foreground factors

ID	Business factors
BTS5	4D Trajectory Management
BTS9	Traffic synchronisation
BTO4	Passenger reaccommodation tools
BEO1	Fuel prices
BEO2	Airspace charges
BEO3	Airline business models (output)
BEO4	Smart, integrated ticketing

ID	Regulatory factors
ROR1	Passenger provision schemes
ROR3	Emission schemes
ROR4	Noise pollution (implicit)
RAD1	Airport slots
RAD2	Regional airport development
RAA1	Airport access
ROR9	Operation of air services

Foreground groups	
EM: Environmental mitigation policies	PF: Passenger focus
RI: Regional infrastructures	SES: Single European Sky

Overview of the model

JIRA

What it is: Project-tracking software
Why we're using it: Shared task definition environment
Scrum/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

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 ranges of metrics, not only delays
- Developed and tested over 7 years of research under several initiatives (SESAR*, H2020) with a range of stakeholders

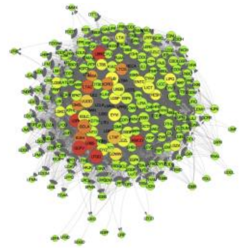
- Mesoscopic (D2D) approach; **stochastic modelling**
- Airline decisions based on **cost models** (e.g. Reg 261) and **rules** (current, or ‘what-if’)
- Includes disruptions, cancellations, re-accommodation and compensation costs
- Incorporates ATM demand/capacity balance model (ATFM slots)

***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

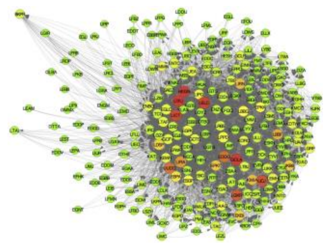


Smaller airports (more) implicated in delay propagation

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



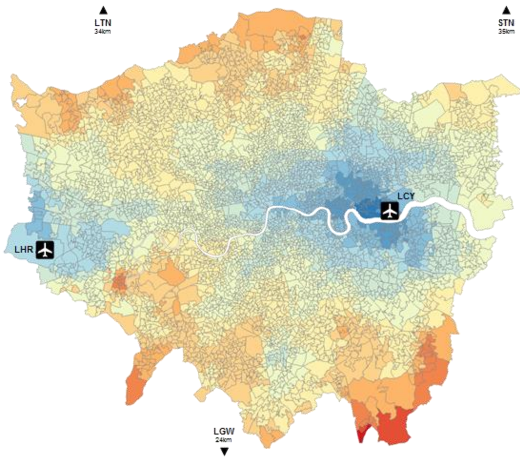
- **… but these communities more susceptible to such propagation**
- **largest persistent airports: Athens, Barcelona & Istanbul Atatürk**

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

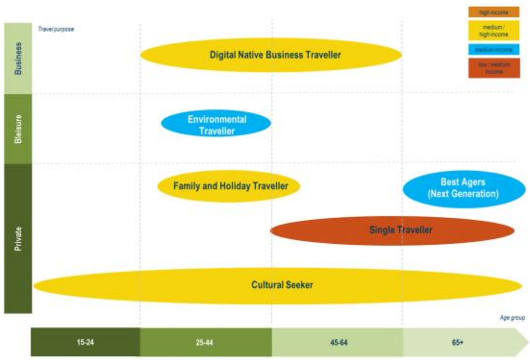
↓ €39	avg. cost / flight (x27k > €1m)
↓ 9.8 mins	avg. arrival-delayed pax
↑ 2%	reactionary delay

The tactical layer

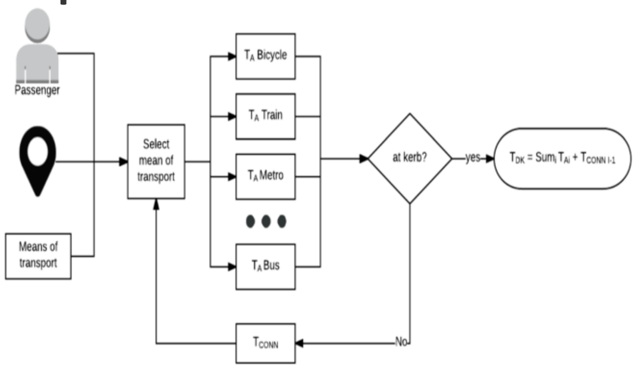
Door-to-door context and 2050 (also courtesy DATASET2050)

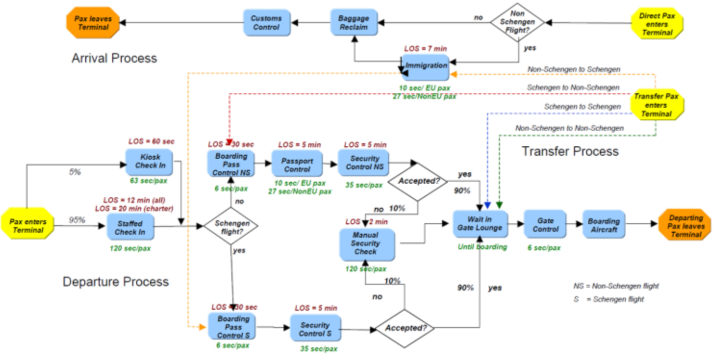


Airport access: data-driven stochastic processes

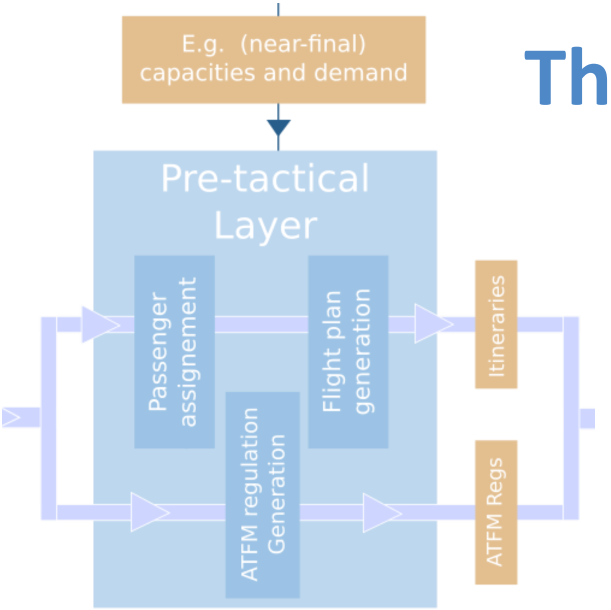


Pax profiles linked with itineraries





Confidential access to airport process times



The pre-tactical layer

The pre-tactical layer

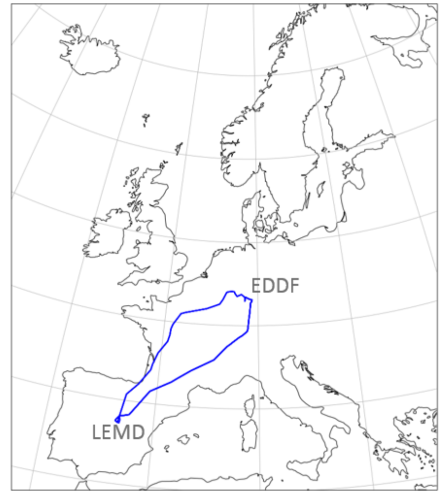
Flight schedules

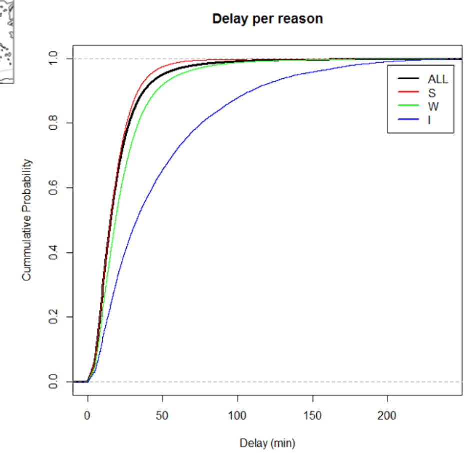
Passenger flows

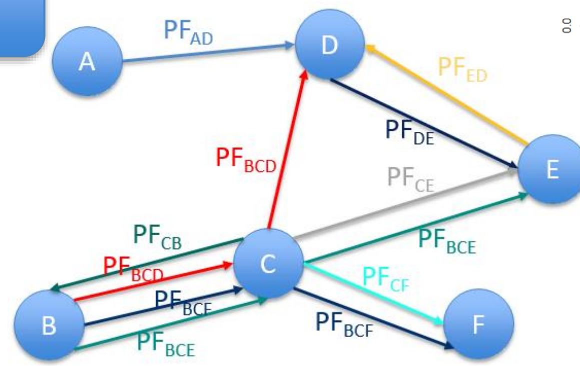
Flight plans

ATFM delays

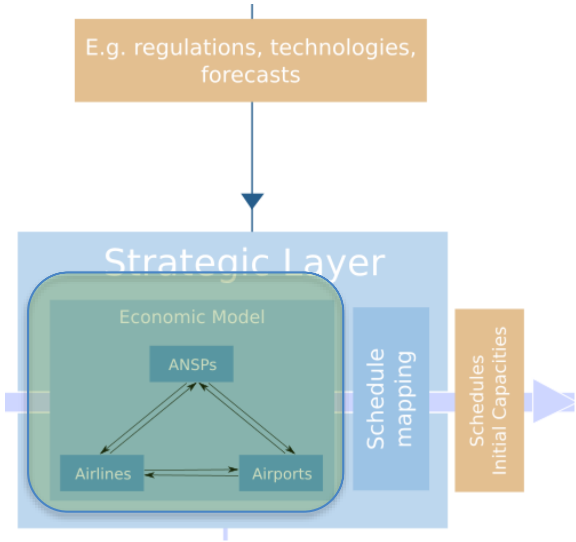
Passenger itineraries







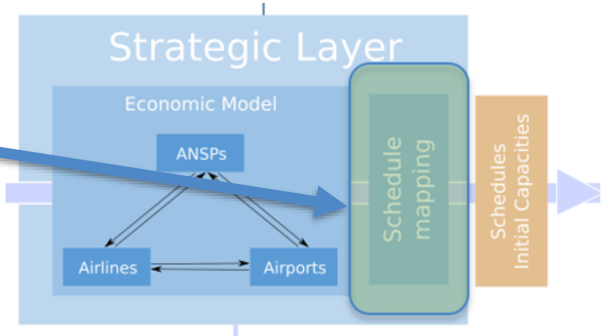
IATA, GDS; MCTs; traffic (high effort)



The strategic layer

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

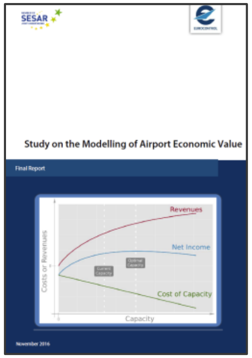
Airport revenues and costs

- 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)



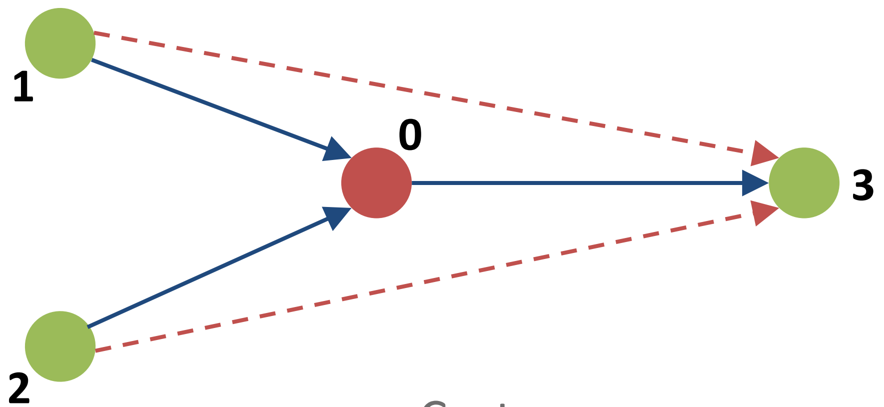
- **passengers** choose between itineraries for given OD pairs
- **selling price** of each itinerary is updated
  - based on balance between supply & demand

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

* availability lagged by several turns

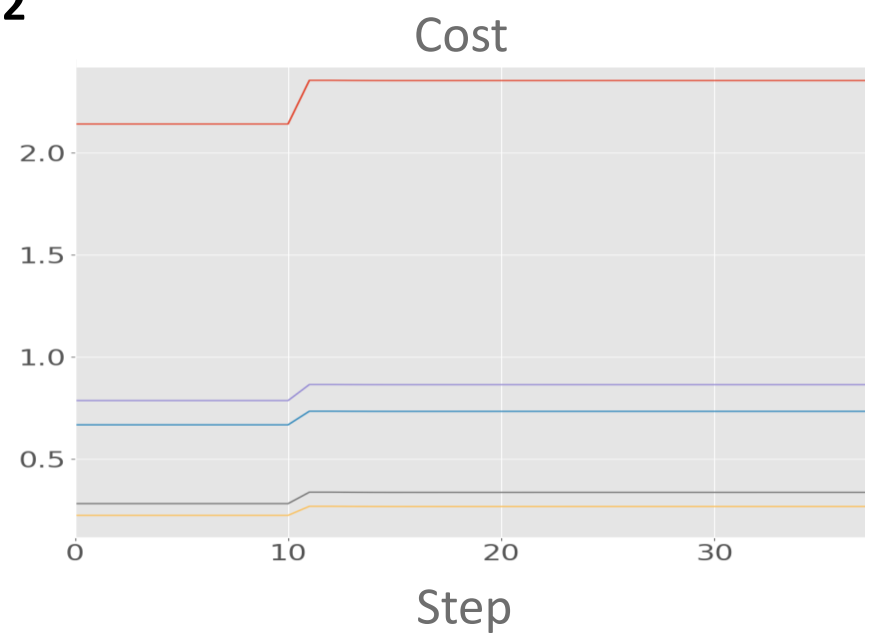
The strategic layer

Simple scenarios to test / illustrate the model



'mainline', hub-based

'low-cost', P2P



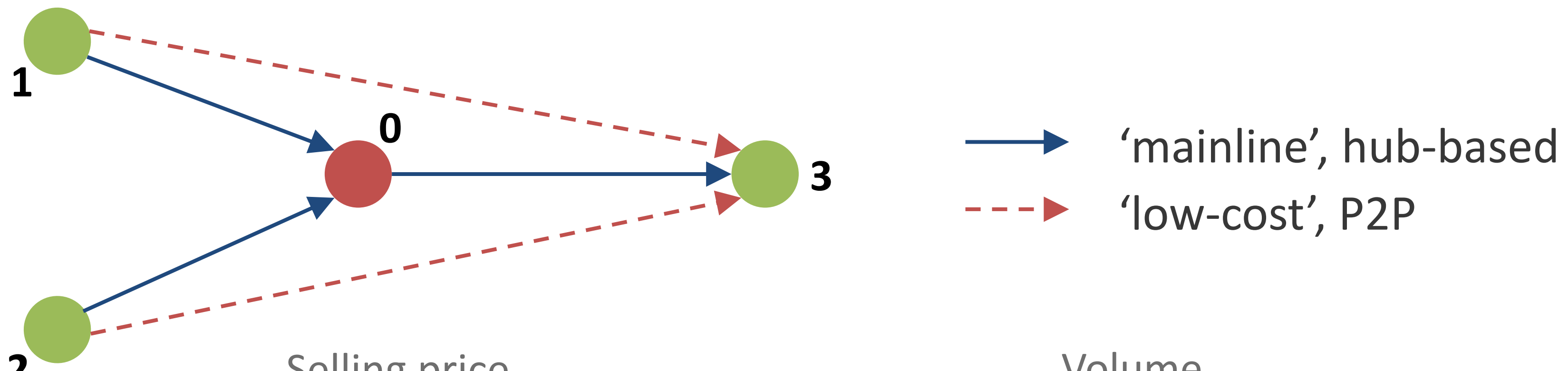
Scenario:

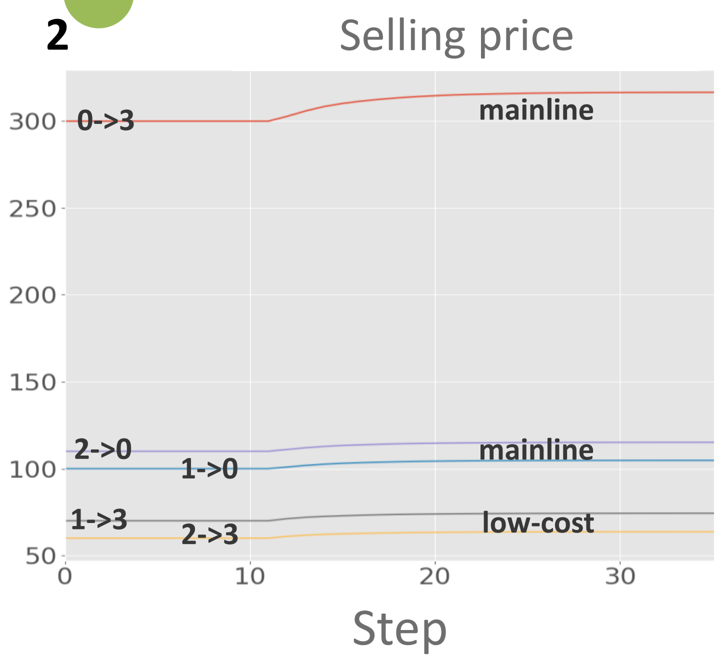
shock (doubling) fuel price

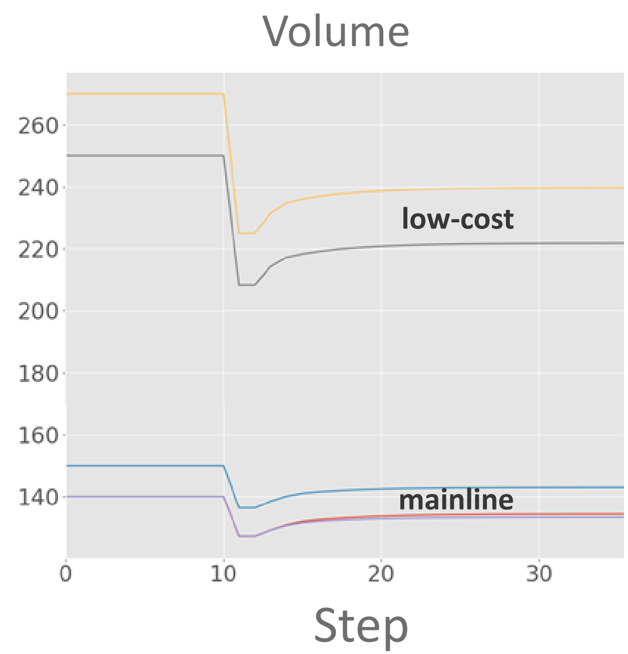
-> costs on all OD pairs increase

The strategic layer

Simple scenarios to test / illustrate the model

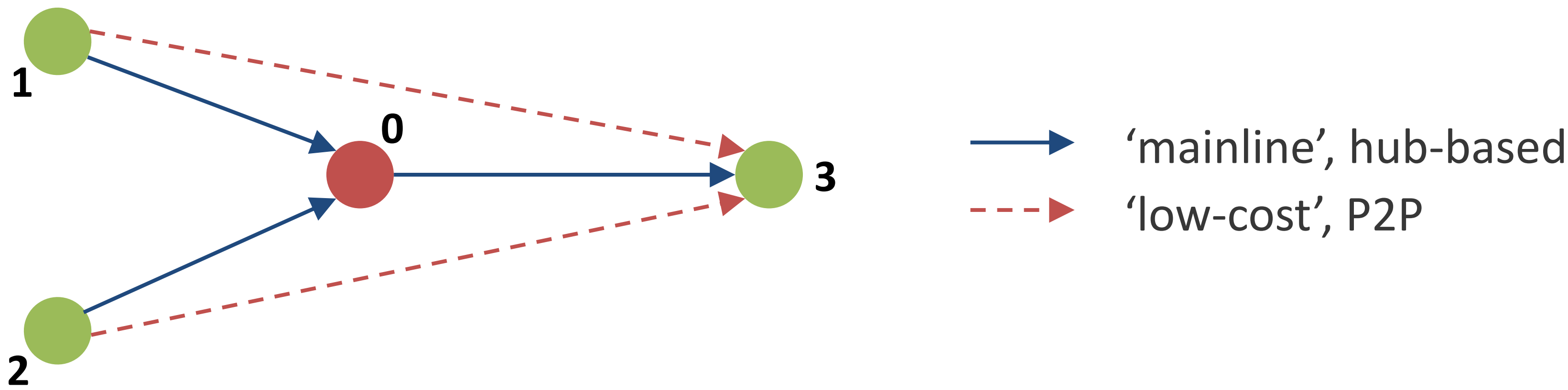




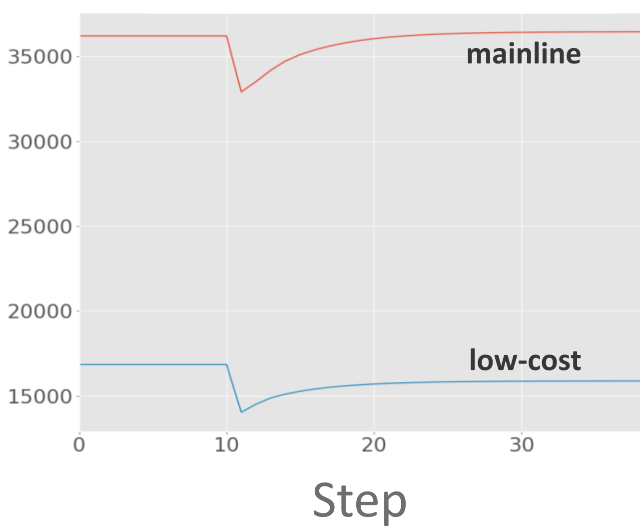


The strategic layer

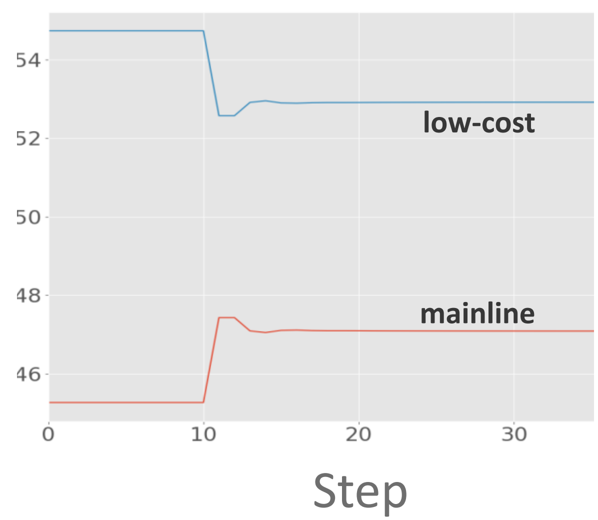
Simple scenarios to test / illustrate the model



Profit



Market share



The strategic layer

Calibration is carried out in several steps:

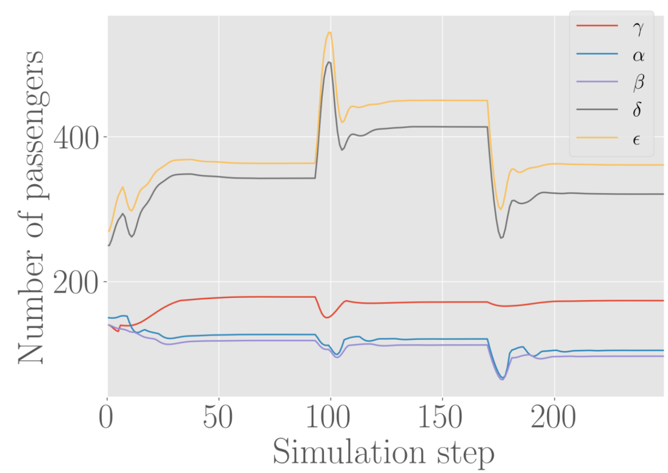
- **Direct calibration**
  - Extract values from historical data (including literature) and put them directly in the model (e.g. pax price elasticity)
  - Assign phenomenological relationships obtained otherwise (e.g. airline cost of delay)

- **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

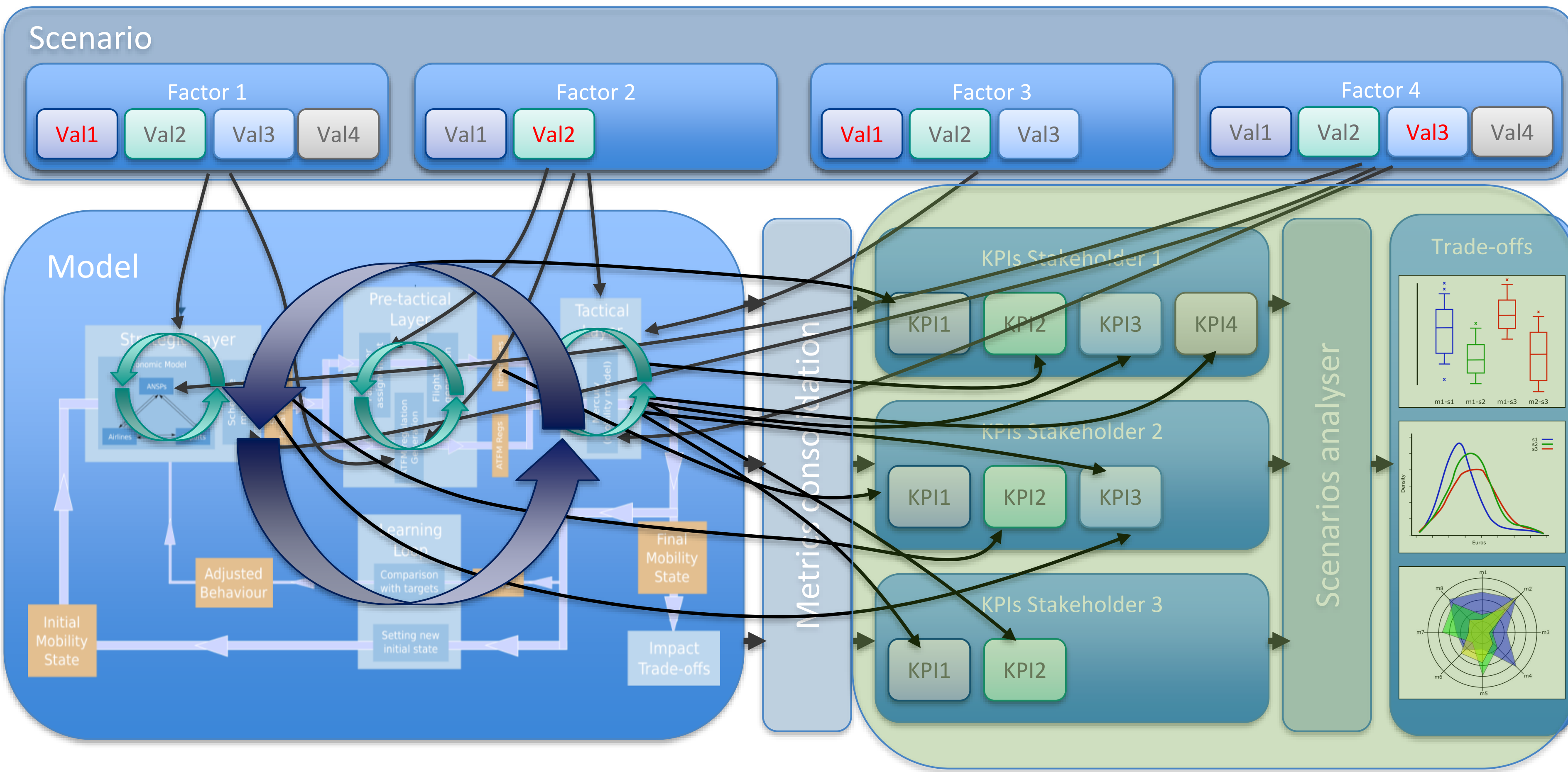
**Rather more detailed examples to share with you,
but too time consuming to include within whole overview**

- local increase in demand
- increase in fuel price
- local capacity increase

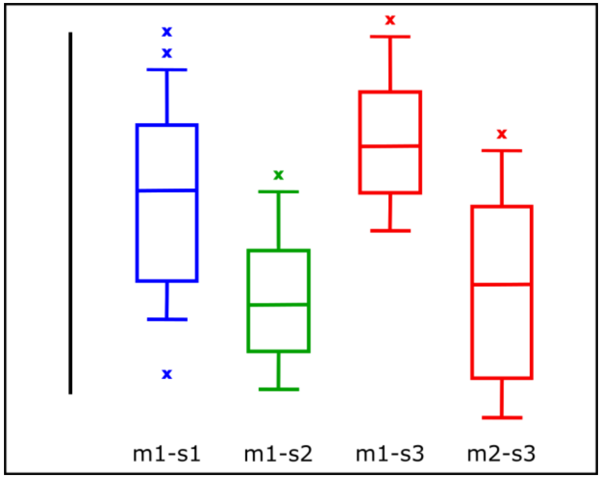


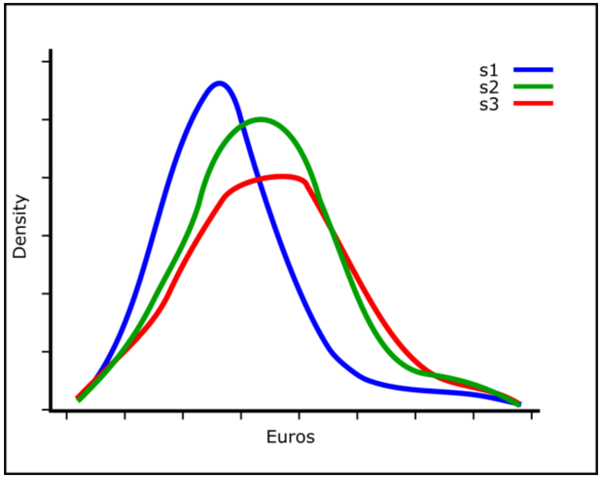
Trade-off analysis

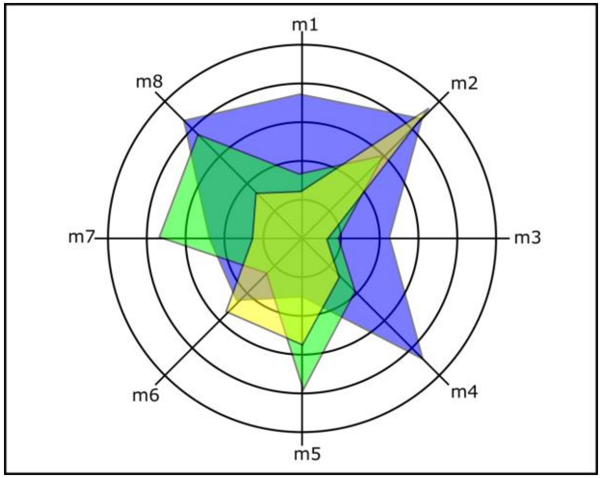
Trade-off analysis



Trade-off analysis







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

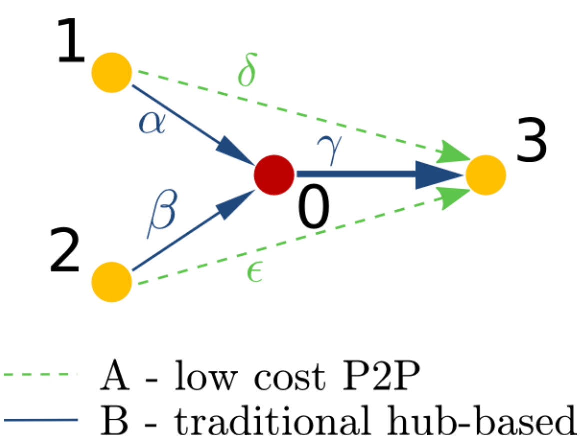
- At this stage in the design process, we'd very much welcome your feedback
- Of course, we're fully open to any questions, too
- For the airlines in particular:
  - Can you quantify the trade-offs between KPIs, such as OTP and market share?
  - For which trade-offs do you have least insight now, but the greatest need?
  - What is your strategic business scanning 'horizon' (2020? 2035?) – and why?
  - How do you do this – in-house? Cross-alliance? Off-the-shelf? Consultancy?
  - 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)?

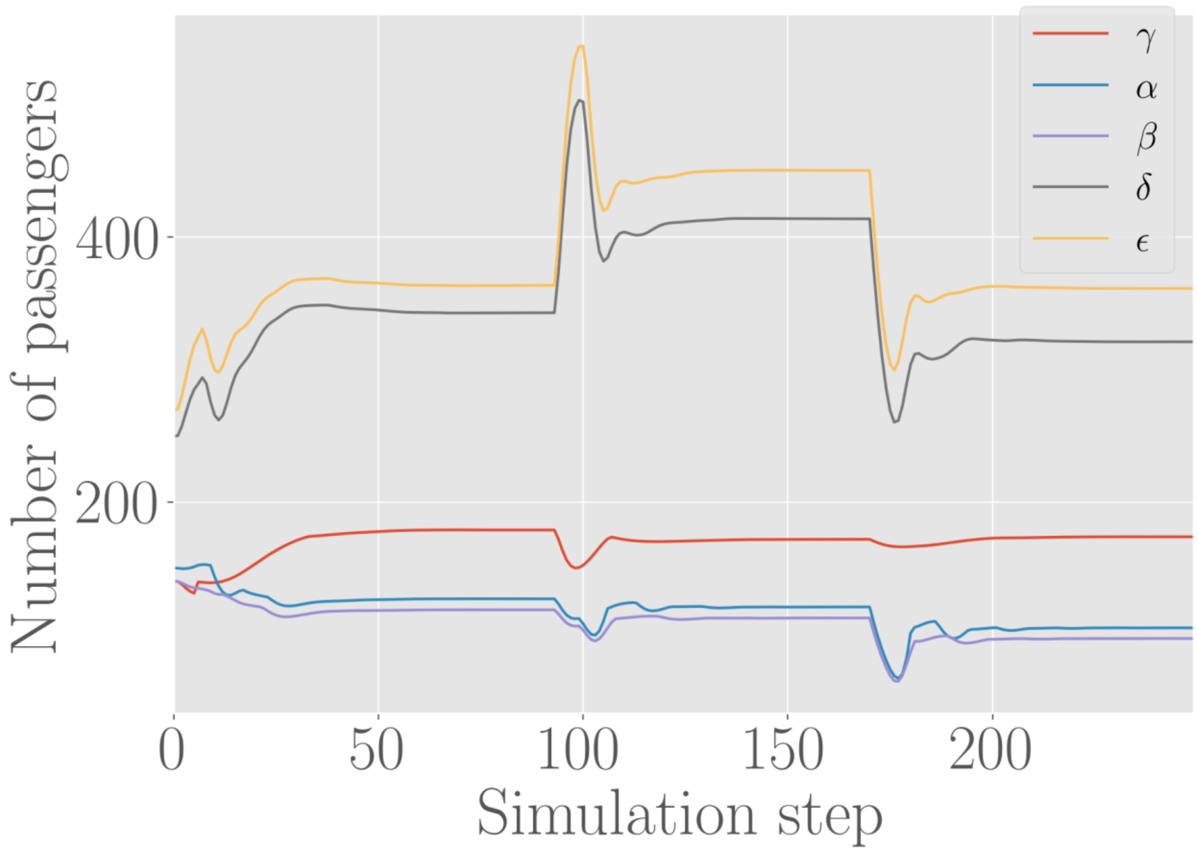
Stand-bys

Metrics

Stakeholder	Metrics	
Passengers	• Number / volume • Delay (departure, arrival; reactionary) • Gate-to-gate time • Door-to-door time	• Missed connections • Hard / soft costs • Value of time (utility)
Airlines	• Number / volume (flights, pax) • Delay (departure, arrival; reactionary) • Revenue and costs (incl. delay)	• Gate-to-gate time (OTP) • Missed connections • Gate-to-gate time
ANSPs	• Number / volume (flights) • Delay (generated, mitigated)	• Flight-km controlled • Revenue and costs (incl. delay)
Airports	• Number / volume (flights, pax) • Delay (departure, arrival; reactionary) • Revenue and costs (incl. delay)	• Missed connections
Environment	• CO_2	• NO_x

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

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

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