Assessing European mobility
Cook, A.J. and Perez, D.


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Assessing European mobility

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Madrid
Overview and objectives

• Modelling developments
  – POEM
  – DATASET2050
  – Vista
  ‘Mercury’ mobility model core capability

• Data visualisation

• Discussion
  – 4H D2D revisited …
  – Concluding remarks (but not conclusions!)
# Overview and objectives

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<td>University of Westminster Innaxis</td>
<td>Current <strong>Gate-to-gate</strong> Pax c.f. flights</td>
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<td>Data-driven pax mobility</td>
<td>EU Research &amp; innovation programme (CSA) (H2020) 2014-17 (CSA)</td>
<td>Innaxis University of Westminster Bauhaus Luftfahrt EUROCONTROL</td>
<td>Current, ≈2035, ≈2050 <strong>Door-to-door</strong> Pax mobility</td>
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<td>KPA trade-offs</td>
<td>SESAR Research &amp; innovation action (H2020) 2016-18</td>
<td>University of Westminster Innaxis Belgocontrol EUROCONTROL Icelandair Norwegian Air Shuttle SWISS</td>
<td>Current, ≈2035, ≈2050 <strong>Door-to-door</strong> Pax mobility Wider stakeholders</td>
</tr>
</tbody>
</table>
POEM
Passenger-Oriented Enhanced Metrics
SESAR Outstanding Project Award
Motivation

• To build a European network simulation model for flights and explicit passengers, which:
  – realistically captures airline decision-making and costs
  – includes a range of new performance metrics:
    – e.g. passenger-centric and propagation-centric
  – operates under a range of flight and pax prioritisation scenarios

• Key objectives, to investigate under these scenarios:
  – performance (cost and delay) trade-offs related tasks
  – propagation of delay through network

• Included stakeholder workshops & two (airline) case studies
Motivation

• Policy-driven motivation
  – ultimate performance delivery to the passenger
  – ACARE Strategic Research & Innovation Agenda (Sep. 2012)
  – Commission's new roadmap (2011) to a Single European Transport Area for 2050: pax mobility & network resilience
  – extension of passenger rights (e.g. review of Regulation 261)

• Operational drivers
  – pax dominate most AO delay costs and therefore strongly influence AO behaviour in the network (strategically and tactically)
  – currently only using flight-centric metrics (Europe & US), although flight delay ≠ pax delay (US factors of 1.6 – 1.7)

• How can we measure specific progress without metrics?
Passengers and costs
Passengers and costs

- 2000: SES launched by Commission
  - specifically in response to increasing delays

- Early 2000s: cost of delay
  - state of the art not very mature
  - no single, comprehensive study meeting industry needs
  - various values; lack of consensus

- University of Westminster started from scratch
  - review of method
  - all minutes are not equal
  - 2002-2004 (260 page ‘summary’)
  - data sources: secondary & primary, extensive interviews
Passengers and costs

• Key objectives of the ‘new’ framework
  – comprehensive & transparent approach
    § including margins of error
  – consultation and industry agreement
    § common reference values
  – operationally meaningful – aligned with AO mind set
    § bottom line in accounts (very challenging); interviews
  – shift the focus away from fuel-only costs
  – useful at network level, e.g. total and average ATFM delays
Passengers and costs

• Key features

  – tactical cost of delay
    § incurred on the day of operations, not planned in advance
    § mostly marginal costs
    § e.g. aircraft waiting at-gate

  – strategic cost of delay (then a new concept)
    § incurred in advance, often difficult to recover later (‘sunk’ cost)
    § mostly unit costs
    § e.g. schedule buffer (‘opportunity’ cost) & route extension (later)

  – passenger cost of delay
    • ‘hard’ cost to AO
    • ‘soft’ cost to AO
    • internalised costs (c.f. US)
Passengers and costs

types of cost (in-house models, except fuel)

- fleet: all fleet costs (depreciation, rentals & leases)
- fuel: Lido/Flight, BADA, manufacturers
- crew: schemes, flight hours, on-costs, overtime
- maintenance: extra wear & tear powerplants/airframe
- passenger: major update in 2010 …
## Passengers and costs

<table>
<thead>
<tr>
<th>Cost element</th>
<th>2004</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pax hard cost</td>
<td>Treated as zero for &lt;15 minutes of delay</td>
<td>Major update - full cost curves (power curve) derived as function of primary delay</td>
</tr>
<tr>
<td>Pax soft cost</td>
<td>Treated as zero for &lt;15 minutes of delay</td>
<td>Major update - full cost curves (logit curve) derived as function of primary delay; scalability now accounted for: small fraction of total now used in most contexts</td>
</tr>
<tr>
<td>Crew</td>
<td>Treated as zero for &lt;15 minutes of delay</td>
<td>Extensive new model addressing crew payment schemes and overtime rates; costs assigned to all delay magnitudes</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Overheads not fully assessed; costs based on block-hour costs</td>
<td>Overheads fully assessed; cost base extended and re-calibrated on full ICAO data sets</td>
</tr>
<tr>
<td>Fleet</td>
<td>Major model developed, based on extensive financial literature</td>
<td>Cost base extended and re-calibrated on full ICAO data sets, supplemented with update from financial literature</td>
</tr>
<tr>
<td>Fuel</td>
<td>0.31 EUR/kg</td>
<td>0.60 EUR/kg; carriage penalty now applied to arrival management</td>
</tr>
<tr>
<td>Reactionary</td>
<td>Two multipliers: one for below 15 minutes of delay, one for above</td>
<td>Extended model: multipliers fully quantified as function of primary delay magnitude, caps applied using new rotationary models</td>
</tr>
</tbody>
</table>
Passengers and costs

- Passenger costs modelling from 2010 (2nd edition)
  - originally Austrian + ‘Airline Z’ (very close), single average value
  - logit curve (soft), power curve (hard) – basic, but $f$ (duration)
Passengers and costs

![Graph showing passengers and costs over delay time (mins) with a primary cost scale in k€. The graph includes a clock, indicating specific delays and costs for B738.](image-url)
Passengers and costs

• Major updates in 2015 (3rd edition) – 2014 cost basis
  – 3 aircraft added (DH8D, E190, A332)
    § now 15 aircraft, 63% coverage of CFMU area
  – rotations per day, service hours, average MTOWs, ATFM delay distributions, seat & load factors; reactionary data – all updated
  – fuel 0.8 €/kg; APU fuel added at-gate (base scenario: 25% running)
  – crew & maintenance: □; fleet: □□ (all continuing 2010 trends)
  – passenger costs: still only limited evidence
    § EC Impact Assessment (Reg. 261) + limited literature (e.g. claim rates)
    § UoW consultation document Aug-Oct15; 400+ contacts (mostly AOs)
    § 8.8% (inflationary) … pax densities => net = 20%
Passengers and costs

- 2014 15-minute distributions very similar to those for 2010
- Pax costs also dominate en-route at higher delays
Key model features
Key model features

• POEM evaluates different flight & pax prioritisation strategies
• Includes tactical costs to the airline (4 AO types)
• Key data-related characteristics of Mercury core model:
  – runs a busy day and month (September 2010 & 2014)
  – non-exceptional in terms of delays, strikes, weather
  – busiest 200 ECAC airports (e.g. 97% pax & 93% traffic, 2010)
  – 50 non-ECAC airports (based on pax flows in/out Europe)
  – extensive range and logic checks (e.g. speeds, registration seqs)
  – taxi-out unreliable; taxi-in missing; IOBT c.f. schedule
  – calibration (independent sources, e.g. network delays and LFs)
• Unique combination of PaxIS and PRISME data …
Key model features

- aggregated PaxIS (IATA ticket) pax data allocated onto individual flights (PRISME traffic data, from EUROCONTROL)
- assignment algorithms respecting aircraft seat configurations and load factor targets
- full pax itineraries built respecting MCTs and published schedules
- 27k flights in scope
- 3.8 million pax
- >150k routings

2014
Key model features

Current passenger data
- 2010 itineraries
- 2014 GDS
- 2010 PaxIS

Current (future) traffic data
- ECAC + 50 external flows

Load factor estimation

Calibration data
- ACI Europe traffic
- Eurostat passenger flows
- Airline load factors
  (Forecast data)

Compute possible routes

Score options

Possible options per itinerary

Possible options per itinerary with scores

Load factor targets

Flight capacities

Route assignment rules

Itineraries assigned

Capacity available

Capacity evaluation

New route itineraries generation

Fare adjustment

Flights with (interim/final) itineraries

Flights with final itineraries
Key model features

- Modular structure, can adapt and add new functionalities
- Varying levels of fidelity, for example:
  - Rule 23: en-route recovery (was very basic, now DCI uptake!)
  - Rule 33: passenger reaccommodation
    - Regulation (EC) 261/2004; IATA (involuntary rerouting & proration rules)
    - trigger: pax late at gate (a/c not wait); cancellation; (denied boarding)
    - aircraft seat configuration data used with routing sub-rules
    - passenger prioritisation sub-rules (alliances, ticket flexibility, ties)
    - hard costs (rebooking, cost of care, overnight accommodation)
    - soft costs (dissatisfaction, market share; capped at 5 hours)
    - (passenger value of time)
    - multiple sources, including airline input and airline review
Key model features

- event-driven: event stack, ordered sequence of events, each with a stamp
- dynamic tracking of costs for each a/c & passenger
- some pre-computed cost functions: recursive (from end of day backwards along propagation tree); discrete dly
- stable after appx. 10 runs
- MATLAB (R2016b)
- 5-20 minutes to run one day (depends on complexity)
- Amazon-cloud grid of five super-computers
Key model features

[...](17-Sep-2010 12:25:00) 47 out of 49 of pax (95.92 pct.) of DLH_EDDLEGGBB02:15877 were ready, flight over 80 pct. occupancy, no more delay added

(17-Sep-2010 12:25:00) Total cost of flight DLH_EDDLEGGBB02:15877 departing at 17-Sep-2010 12:25:00 now estimated at 127.15 euros (DUS-BHX)

(17-Sep-2010 12:25:00) No further pax delay will be introduced, thus flight DLH_EDDLEGGBB02:15877 is now pushback ready, reaccommodating connecting pax

(17-Sep-2010 12:25:00) Pax group DLH1815:37550 of 2 inflex pax coming from DLH_EDDHELDDLO6:12246 to EGBB did not make it to DLH_EDDLEGGBB02:15877 (no more connections afterwards) and need to be reaccommodated

(17-Sep-2010 12:25:00) 2 inflex pax of group DLH1815:37550 of DLH_EDDHELDDLO6:12246 that missed DLH_EDDLEGGBB02:15877 were successfully reaccommodated in DLH_EDDLEGGBB03:23396 same alliance, DLH1815/1:145607 Arrival: 17-Sep-2010 17:50:00 delay: 04:00'00" (airport wait 03:01'51"

(17-Sep-2010 12:25:00) Trying to reaccommodate the 80 pax waiting at EDDL:10 (DUS)

(17-Sep-2010 12:25:00) A total of 2 pax of DLH_EDDLEGGBB02:15877 were left behind and all of them were successfully reaccommodated

(17-Sep-2010 12:25:00) Flight SAS_ENKBMG03:15843 loading 67 pax and all of the 67 pax are not coming from a previous flight. There are NO connecting pax

(17-Sep-2010 12:25:00) There are 29 pax groups in SAS_ENKBMG03:15843 connecting with another flight afterwards (SAS3310:87574, SAS3311:87575, SAS3312:87576, SAS3313:87577, SAS3314, [...]

(KSU-OSL)
Scenarios and selected results
## Scenarios and selected results

<table>
<thead>
<tr>
<th>Type, and level</th>
<th>Designator</th>
<th>Summary description</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-scenario, 0</td>
<td>$S_0$</td>
<td>No-scenario baselines (reproduces historical operations for baseline traffic day)</td>
</tr>
<tr>
<td>ANSP, 1</td>
<td>$N_1$</td>
<td>Prioritisation of inbound flights based on simple passenger numbers</td>
</tr>
<tr>
<td>ANSP, 2</td>
<td>$N_2$</td>
<td>Inbound flights arriving more than 15 minutes late are prioritised based on the number of onward flights delayed by inbound connecting passengers</td>
</tr>
<tr>
<td>AO, 1</td>
<td>$A_1$</td>
<td>Wait times and associated departure slots are estimated on a cost minimisation basis, with longer wait times potentially forced during periods of heavy ATFM delay</td>
</tr>
<tr>
<td>AO, 2</td>
<td>$A_2$</td>
<td>Departure times and arrival sequences based on delay costs – $A_1$ is implemented and flights are independently arrival-managed based on delay cost</td>
</tr>
<tr>
<td>Policy, 1</td>
<td>$P_1$</td>
<td>Passengers are reaccommodated based on prioritisation by final arrival delay, instead of by ticket type, but preserving interlining hierarchies</td>
</tr>
<tr>
<td>Policy, 2</td>
<td>$P_2$</td>
<td>Passengers are reaccommodated based on prioritisation by final arrival delay, regardless of ticket type, and also relaxing all interlining hierarchies</td>
</tr>
</tbody>
</table>
Scenarios and selected results

• $A_1$ and reactionary delay
  – increases from 49% ($S_0$) to 51% as a proportion of all dep. delay
  – … but focused on relatively few (waiting) aircraft (purposefully)
  – … saving in total costs wholly due to reduction in hard costs
  – explicit estimations of reactionary delay: a significant advance

• Smaller airports implicated in delay propagation
  – more than hitherto commonly recognised
  – expedited turnaround; spare crew (& a/c); connectivity & capacity

• Back-propagation important in persistence of network delay
  – CDG, MAD, FRA, LHR, ZRH, MUC: all > 100 hours (baseline day)
  – most delay distributed between a relatively limited no. of airports

• Granger causality in complex network theory context …
Flight delay causality network for $S_0$

redder => higher connectedness (E)  larger => more nodes ‘forced’ (out-degree)
Flight delay causality network for $A_1$
Scenarios and selected results

• Main conclusions of Granger causality analyses
  – all four layers very different, i.e. airports play different roles in terms of flight and passenger delay propagation, and different again under A₁

• Main effects of A₁ (cost-minimising aircraft wait rules)
  – delay propagation contained within smaller airport communities
  – … but these communities more susceptible to such propagation
  – largest persistent airports: Athens, Barcelona & Istanbul Atatürk
  – all scenarios: no stat. signif. changes in current flight-centric metrics!
    - €39 avg. cost / flight
    - 9.8 mins avg. arr. / dlyd pax
    - 2% reactionary delay
DATASET2050
Data-driven approach for seamless, efficient European travel in 2050
>95% of flights arrival delay ≤ 3 mins (2020);
0.5 mins/flt (2015-19).
Key questions

• What is the current D2D time?
  – how can we improve without quantifying appropriate metrics?

• How achievable is the 4H D2D ambition by 2050?
  – demand? (more later …) supply-driven?
  – where is the key compressibility? regulatory (e.g. Reg 261) role?
  – disruptive change required? – e.g. journey ownership, pax data mgt

• EU 28 and EFTA, plus extra-European flows

• What is the cost/benefit ratio? What if we do nothing?
Key trade-offs

<table>
<thead>
<tr>
<th>Large spend</th>
<th>Small spend</th>
</tr>
</thead>
<tbody>
<tr>
<td>90%</td>
<td>10% (shape &amp; metrics)</td>
</tr>
<tr>
<td>Travel</td>
<td>Technology (+&amp;-) &amp; env.</td>
</tr>
<tr>
<td>Competition</td>
<td>Cooperation &amp; responsibility</td>
</tr>
<tr>
<td>Airline profitability (LFs)</td>
<td>Network resilience</td>
</tr>
<tr>
<td>Airport profitability (non-aero)</td>
<td>Pax dwell times</td>
</tr>
</tbody>
</table>
Building a picture for 2050

• Model framework: high-level factor groups
  – H1. Traffic / demand
  – H2. Market forces / technologies / supply
  – H3. Policy / regulation

• Populate with: future European passenger archetypes
  – data-driven, evidence-based (better availability for 2035)
  – multiple data sources & factors considered (e.g. ICT use, education)
  – 65+ group around 25% of population in 2035 (‘Best Agers’)
  – passengers may belong to more than group
Building a picture for 2050

**2035**

**Best Agers (Next Generation)**

- **Main Travel Purpose:** Private
- **Predominant Age Group:** 65+
- **Travel Activity:** 0.5 Trips / Year
- **Income Level:** 
  - € € € €
- **Expenditure on Transport:**
  - Train, Car, Plane, Bicycle
- **ICT Usage:**
  - Mobile, Computer
- **Travel Party Size:**
  - Small, Large
- **Check-In Luggage:**
  - Small, Medium, Large
- **Access Mode Choice:**
  - Walk, Bike, Car, Train, Air
Building a picture for 2050

- Digital Native Business Traveller
- Environmental Traveller
- Family and Holiday Traveller
- Best Ages (Next Generation)
- Single Traveller
- Cultural Seeker

Travel purpose

Age group:
- 15-24
- 25-44
- 45-64
- 65+
Building a picture for 2050
Building a picture for 2050

- Access and egress
  - by mode
  - by time of day
  - OpenStreetMap; Google; other apps
  - websites (incl. airport access tools)
  - timetables (primary data)
  - market research
  - wider literature (journals, reports, accessibility plans)
<table>
<thead>
<tr>
<th>High-level factor group</th>
<th>Model scenario 1: WEAK supporting changes</th>
<th>Model scenario 2: EXPECTED supporting changes</th>
<th>Model scenario 3: STRONG supporting changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1. Traffic / demand</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Door-to-kerb</td>
<td><strong>NET</strong></td>
<td>LOW</td>
<td>LOW</td>
</tr>
<tr>
<td>... Future traffic</td>
<td>Low</td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>... HSR substitution</td>
<td>Low</td>
<td></td>
<td>Medium</td>
</tr>
<tr>
<td>Kerb-to-gate</td>
<td><strong>NET [...]</strong></td>
<td>LOW</td>
<td>MEDIUM</td>
</tr>
<tr>
<td>Gate-to-gate</td>
<td><strong>NET [...]</strong></td>
<td>LOW</td>
<td>MEDIUM</td>
</tr>
<tr>
<td>H2. Market forces / technologies / supply</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Door-to-kerb</td>
<td><strong>NET [...]</strong></td>
<td>LOW</td>
<td>MEDIUM</td>
</tr>
<tr>
<td>Kerb-to-gate</td>
<td><strong>NET</strong></td>
<td>LOW</td>
<td>MEDIUM</td>
</tr>
<tr>
<td>... Seamless ticketing</td>
<td>Low</td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>... Self-service take-up</td>
<td>Low</td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>... Baggage handling</td>
<td>Low</td>
<td></td>
<td>Medium</td>
</tr>
<tr>
<td>... Security processes</td>
<td>Low</td>
<td></td>
<td>Medium</td>
</tr>
<tr>
<td>Gate-to-gate</td>
<td><strong>NET [...]</strong></td>
<td>LOW</td>
<td>MEDIUM</td>
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<tr>
<td>H3. Policy / regulation</td>
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<td><strong>NET [...]</strong></td>
<td>LOW</td>
<td>MEDIUM</td>
</tr>
</tbody>
</table>
Building a picture for 2050

- Two largest effects (??)

- Access times
  - driven by technology (travel supply) & regulation

- Dwell (buffer) times
  - driven by airport policy (revenue) & regulation (?)

- Policy implications
Vista

Examines effects of conflicting market forces on European performance, through evaluation of fully monetised & quasi-cost impact metrics on four stakeholders, and the environment
Assessing impacts

- **Business (market) factors** (incl. tools & technologies) may conflict with (new) **regulations** (and instruments) [review]

- Exploring unintended consequences, such as:
  - 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 detect$^N$)
  - monetised (e.g. cost of delay; ATCOs) & quasi-cost ($NO_x$, $\sigma^2_{arr}$)

- **Stakeholders**
  - passengers, airlines, ANSPs, airports; environment
KPIs established for 2015 (all in SES PS, RP2)
2015 (start of SES RP2; Master Plan Edition 3)

2035 (SESAR performance ambitions; ≈ doubling of 2005 traffic)

2050 (Flightpath 2050 vision)

business forces

regulatory forces
‘Mercury’ model: at core of evaluation framework

Ambition: TRL2 (technology concept and/or application formulated; applied research)

Trade-off analysis: Pareto frontier; expected utility; Granger causality; precursor-successor analysis
Assessing impacts

• Better understanding of future KPA roadmap & interactions
• Supporting industry to better adapt to change
• Reducing the risk of future performance misalignment and unintended consequences
• Improving the potential of implementing synergistic targets and cost-efficient policy and regulatory measures
• Supporting specific initiatives, such as:
  – improving the gap analysis set as a goal of Network Strategy Plan
  – driving quantified rather than reportedly “conceptual” trade-off assessments in FAB Performance Plans (required by Perf. Reg.)
  – providing extended insights into metric trade-offs for future editions of ATM Master Plan & SES PS planning horizons
  – highlighting further research needs towards ACARE 4H D2D goal
Regulatory example

• Regulation (EC) No 261/2004
  – establishes the rules for compensation and assistance to airline passengers in the event of denied boarding, cancellation or delay
  – came into effect on 17 February 2005
  – implementation across Europe not consistent
  – case law and national rulings have a decisive impact; legally binding European Court of Justice rulings (also interpretive guidelines)
  – consultation: but lack of agreement on proposed changes
  – 2014: proposed strengthening passed first reading in European Parliament; awaiting European Council (member states) agreement

• Complicated in practice, especially regarding ‘extraordinary circumstances’, and reactionary delays – legal advice
## Regulatory example

<table>
<thead>
<tr>
<th>Haul</th>
<th>≥ 90 mins</th>
<th>≥ 2 hours</th>
<th>≥ 3 hours</th>
<th>≥ 4 hours</th>
<th>≥ 5 hours</th>
<th>≥ 8 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short haul</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>+□</td>
</tr>
<tr>
<td>Medium haul</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>+□</td>
</tr>
<tr>
<td>Long haul</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>+□</td>
</tr>
</tbody>
</table>

**Key**

- ⚫ Care (e.g. reasonable meals and refreshments)
- ⚫ Reimbursement of ticket
- € Compensation (refers to arrival delay)
- © Rights re. missed connecting flights
- ® Better rights re. re-routing on other airlines
- * For delays of three to four hours (CJEU ruling, 2009)

**Orange:** 2005

**Blue:** 2009

**Red:** ??

- **Benefit of more radical regulatory change, beyond 261?**
Forefront Factors

Scenario

Exogenous Variables

Environment

E.g. regulations, technologies, forecasts

E.g. (near-final) capacities and demand

E.g. uncertainty, cost of delay, reaccommodation rules

Strategic Layer

Pre-tactical Layer

Tactical Layer

Economic Model

ANSPs

Schedule mapping

Airlines

Airports

Passenger assignment

ATFM regulation

Flight plan generation

Mercury (mobility model)

Inletries

ATFM Regs

Initial Mobility State

Adjusted Behaviour

Learning Loop

Comparison with targets

Setting new initial state

KPIs

Final Mobility State

Visualisation
Data visualisation
null
Discussion

4H D2D revisited …
• Just a minute … will 90% of travellers actually want 4H D2D in 2050?
• More speed => more stress? Changing social norms?
• Current Call: how will ICT applications (e.g. wifi) tend to reduce the perceived cost of travel time? Examine the potential shift away from the ‘speed paradigm’. Segmentations, and transport project CBA impacts …

Topic: mobility for growth; pillar: societal challenges; work programme part: smart, green and integrated transport
Discussion

Concluding remarks (but not conclusions!)
Concluding remarks

• Early mobility modelling has established the need for passenger-centric and cost-centric metrics
• Capabilities and plans regarding the most developed European model (‘Mercury’) have been presented; this model is laying foundations for further development
• There is still a lot to be done, in particular to:
  – build a full, mature, intermodal European mobility model
  – develop new mobility metrics for the future (RP3 and beyond)
  – move closer towards data-driven policies (e.g. pax-resilient networks)
  – integrate such models and metrics with SESAR (e.g. UDPP, A-CDM)
  – use these to help (e.g.) airlines to develop better strategies
  – examine performance of particular airlines, routes, airports (c.f. network)
  – integrate such models with industry tools (tactical and strategic)
Thank you

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David: dp@innaxis.org
Stand-bys
Cost of delay
Trends and headlines

- Primary at-gate increase: 18%; en-route: 22% (c.f. 2010)

<table>
<thead>
<tr>
<th>Table 30. European ATFM delay cost estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
</tr>
<tr>
<td>Average cost of delay of an ATFM-delayed aircraft</td>
</tr>
<tr>
<td>ATFM delay cost averaged over all flights</td>
</tr>
<tr>
<td>Network average cost of ATFM delay, per minute</td>
</tr>
</tbody>
</table>

*Costs in Euros. 2014 delay weights use 2014 ATFM data.*

NB. The decrease in the ATFM delay cost averaged over all flights is driven by a decrease in the number of flights with ATFM delay as a percentage of all flights, from 7.9% in 2010 to 5.2% in 2014.
Users and example SESAR projects

- EUROCONTROL (EHQ & EEC); SESAR
  - tactical and strategic, planning and assessment levels
- Airlines (two-way process); Working Group
- ANSPs, airports, national government
  - expansion and privatisation
- Legal cases (large delay compensation claims)
- Industry (e.g. delay management software)
- Academia (more global reach c.f. above)
POEM
<table>
<thead>
<tr>
<th>Core metric</th>
<th>Units</th>
<th>Definition</th>
<th>Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flight departure delay</td>
<td>mins / flight</td>
<td>Delay from the gate relative to schedule</td>
<td>0.2</td>
</tr>
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<td>Departure delay of departure-delayed flights</td>
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<td>1.0</td>
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<td>Arrival delay of arrival-delayed flights</td>
<td>mins / flight</td>
<td>Delay at the gate relative to schedule</td>
<td>1.0</td>
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<tr>
<td>Pax departure delay</td>
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<tr>
<td>Passenger hard cost</td>
<td>Euros / pax</td>
<td>Hard costs (see Appendix A) averaged per passenger</td>
<td>0.2</td>
</tr>
<tr>
<td>Passenger soft cost</td>
<td>Euros / pax</td>
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</tr>
<tr>
<td>Passenger value of time</td>
<td>Euros / pax</td>
<td>Pax value of time (see Appendix A) averaged per passenger</td>
<td>0.2</td>
</tr>
<tr>
<td>Non-passenger costs</td>
<td>Euros / flight</td>
<td>Fuel, crew and maintenance costs averaged per flight</td>
<td>10</td>
</tr>
<tr>
<td>Per-flight pax hard cost</td>
<td>Euros / flight</td>
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<tr>
<td>Total flight cost</td>
<td>Euros / flight</td>
<td>Passenger plus non-passenger costs per flight</td>
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</tr>
<tr>
<td>Total flight cost per minute of departure delay</td>
<td>Euros / min</td>
<td>Pax plus non-pax costs per minute of departure delay</td>
<td>2.0</td>
</tr>
<tr>
<td>Reactionary delay ratio</td>
<td>ratio</td>
<td>Reactionary delay (see Section 2.5) / flight departure delay</td>
<td>n/a</td>
</tr>
<tr>
<td>Arrival-delayed passenger / flight ratio</td>
<td>ratio</td>
<td>Arrival delay of arrival-delayed pax / arrival-delayed flights</td>
<td>n/a</td>
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### Flight-Centric New Metrics

<table>
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<tr>
<th>Core Metric</th>
<th>Units</th>
<th>N₁ &amp; N₂</th>
<th>P₁</th>
<th>P₂</th>
<th>A₁</th>
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No significant changes in current flight-centric metrics: stresses need for passenger-centric metrics.

Revised passenger rebooking rules produce only weak improvements whilst current airline interlining rules are preserved, c.f. →

- Reactionary delay ratio:
  - N₁: 49%
  - N₂: 51%
Granger causality

- **Key features and results**
  - time series, q, is considered to Granger-cause another time series, p, if inclusion of past values of q can improve forecasting of p
  - two time series with a high correlation
  - two time series ‘forced’ by a third system
  - built flight and pax networks for S₀ and A₁
  - time series of arrival delay for node pairs (unweighted directed network)
  - for each node, calculated eigenvector centrality: delay connectedness
  - comparing eigenvector centrality rankings through Spearman rank correlation coefficients: all four layers almost completely different
Selected key results

Scenario A₂

- addition of independent, cost-based arrival management apparently foiled the benefits of A₁ due to lack of coordination between departures and arrivals
- reflected in higher dispersion (σ) of all core metrics and the highest reactionary delay ratio (58%)
- arrival queuing may have non-linear delay multiplier effects in the network (Kwan and Hansen (2011))
Vista
## ATM Master Plan (Edition 2015)

### SESAR performance ambitions for 2035 (categorised by KPA)

<table>
<thead>
<tr>
<th>Key performance area</th>
<th>SES High-Level Goals vs. 2005</th>
<th>Key performance indicator</th>
<th>SESAR ambition vs. baseline 2012</th>
<th>Absolute saving</th>
<th>Relative saving</th>
</tr>
</thead>
</table>
| **Cost efficiency: ANS productivity** | Reduce ATM services unit cost by 50% or more | • Gate-to-gate direct ANS cost per flight  
- Determined unit cost for en-route ANS*  
- Determined unit cost for terminal ANS* | EUR 290-380 | 30-40% |
| **Operational efficiency** | | • Fuel burn per flight (tonne/flight)  
• Flight time per flight (min/flight) | 4-8 min  
0.25-0.5 tonne | 5-10% |
| **Capacity** | Enable 3-fold increase in ATM capacity | • Departure delay (min/dep)  
- En-route air traffic flow management delay*  
- Primary and reactionary delays all causes  
- Additional flights at congested airports (million)  
- Network throughput additional flights (million) | 1-3 min  
0.2-0.4 (million)  
7.6-9.5 (million)  
Additional flights, not saving | 10-30% |
| **Environment** | Enable 10% reduction in the effects flights have on the environment | • CO₂ emissions (tonne/flight)  
- Horizontal flight efficiency (actual trajectory)*  
- Vertical efficiency  
- Taxi-out phase | 0.79-1.6 tonne | 5-10% |
| **Safety** | Improve safety by factor 10 | • Accidents with ATM contribution | No increase in accidents | Improvement by a factor 3-4 |
| **Security** | | • ATM related security incidents resulting in traffic disruptions | No increase in incidents | |

* Targeted by the Performance Scheme

Metrics with monetary value in business view.
## Regulation 261 - practice

### Summary of Regulation 261 compensation payments assigned by delay types

<table>
<thead>
<tr>
<th>Delay code</th>
<th>Type of delay</th>
<th>Approximate percentage (a)</th>
<th>Compensation paid for primary delay</th>
<th>Compensation paid for reactionary delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>'A'</td>
<td>ANS / ATFM (mostly)</td>
<td>13%</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>'TW'</td>
<td>Turnaround and (non-ATFM) weather (b)</td>
<td>40%</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>'R'</td>
<td>Reactionary</td>
<td>47%</td>
<td>If type 'TW'</td>
<td>If type 'TW'</td>
</tr>
</tbody>
</table>

(a) Estimates based on EUROCONTROL (2014) and EUROCONTROL (2015a). ( Strikes are subsumed across these categories (data not explicitly shown in reports), probably mostly as 'A'.)

(b) Mostly aircraft turnaround; this will include some exempted (exceptional) weather, but this is likely to be a rather low proportion and thus neglected, and even this sub-category still triggers reactionary compensation in any case.