New insights into delay propagation?

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Presented at the 3rd INFORM Airline Forum, Lisbon, 20 - 22 May 2015.

New insights into delay propagation

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Overview

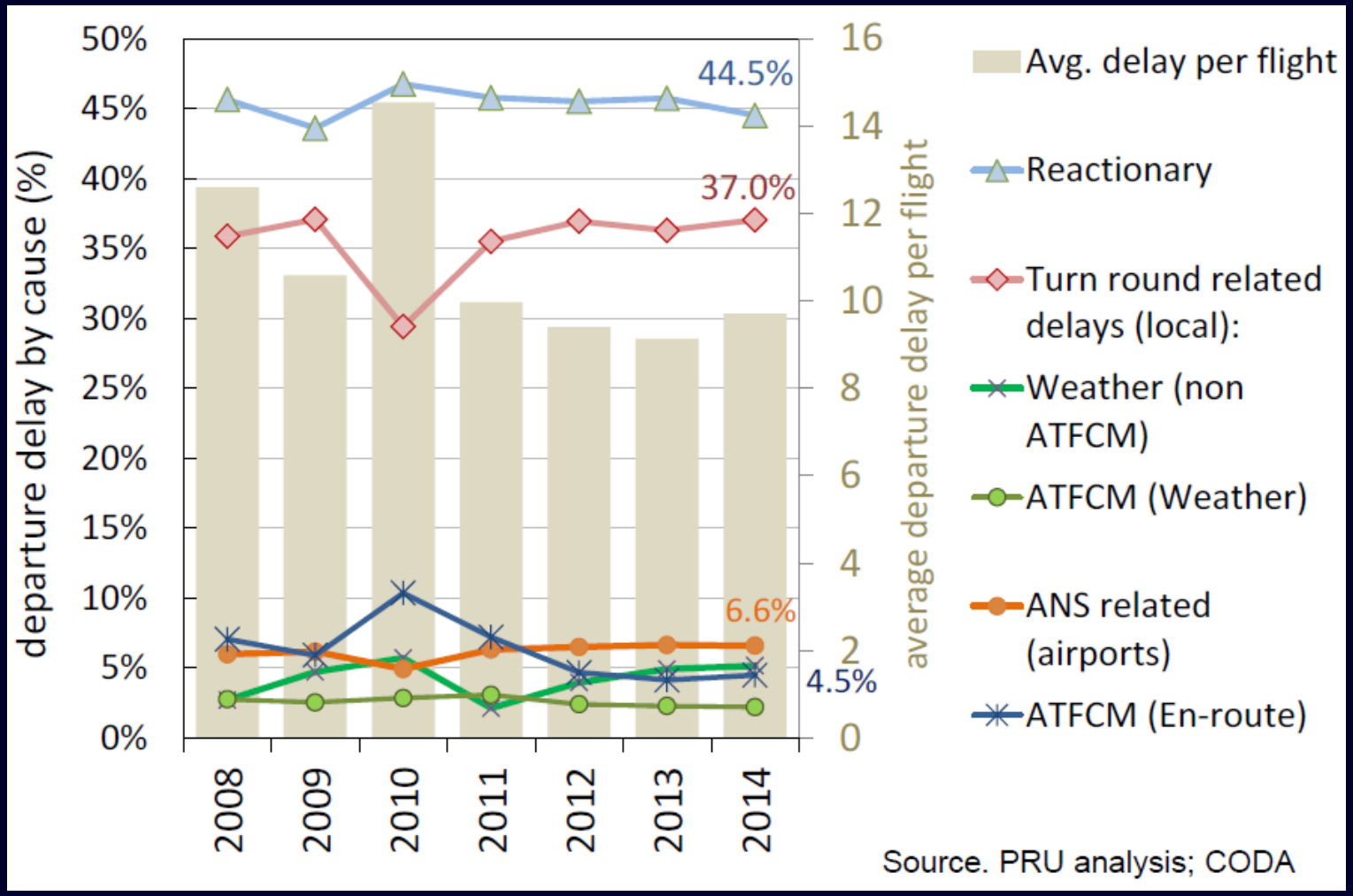
- Delays and passengers in context
- The POEM model
  - delay costs
  - structure and rules
  - key results
- Where next?
  - with the tool
  - funded opportunities from SESAR
  - challenges for A-CDM

Delays and passengers in context

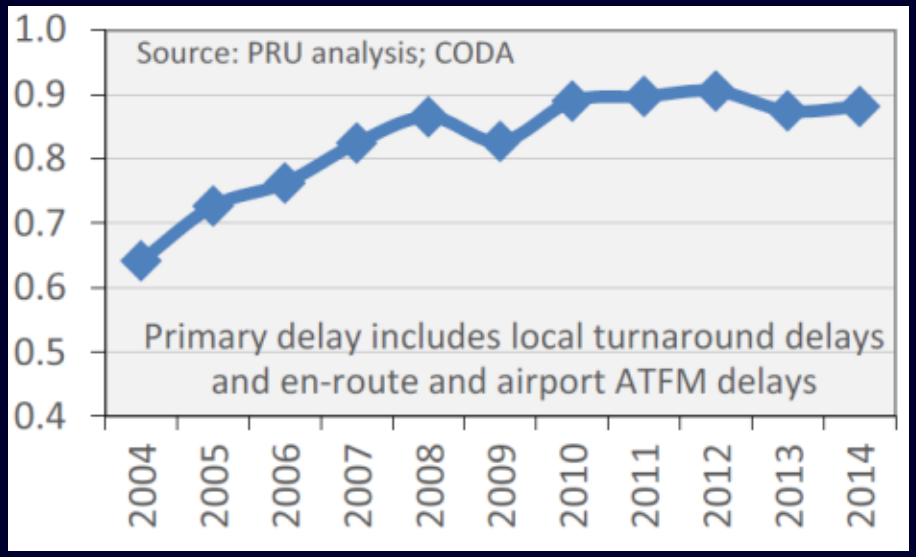
Delays and passengers in context

- Political motivation re. pax mobility, e.g. Commission:
  - roadmap to a Single European Transport Area for 2050 (2011)
  - 'Flightpath 2050', HLG on Aviation Research (2011)
    … 4 hour door-to-door target for 90% of passengers
  - on-going reviews to Regulation 261/2004 (2016?)
- Operational motivation
  - pax direct costs often dominate AO cost of delay (& behaviour)
  - even in pure G2G context, passenger delay > flight delay
- How are we doing now, regarding performance?

Delays and passengers in context



Delays and passengers in context



Ratio of reactionary to primary delay
Each primary minute => ≈0.9 reactionary
(intra-European flights)

- 2014 traffic +1.7%, pax 5.4% (regionality; recover 2008 by 2016)
- Average pax arrival delay? Average D2D?
  - no specific metrics – how measure?
- POEM: Passenger-Oriented Enhanced Metrics
  - putting the passenger at the centre of service delivery
  - exploring new prioritisation strategies using new metrics

The POEM model

- delay costs

Delay costs

types of cost	(in-house models, except fuel)
fleet	*all fleet costs* (depreciation, rentals & leases)
fuel (& CO_2)	Lido/Flight, BADA, manufacturers
crew	schemes, flight hours, on-costs, overtime
maintenance	extra wear & tear powerplants/airframe
passenger	'hard' & 'soft' (not internalised costs)

- Low/base/high scenarios, non-linear, new values for 2014
- Includes brand new assessment of Regulation 261 costs

B733, B734, B735, B738, B752, B763, B744, A319, A320, A321, AT43, AT72, DH8D, E190, A332

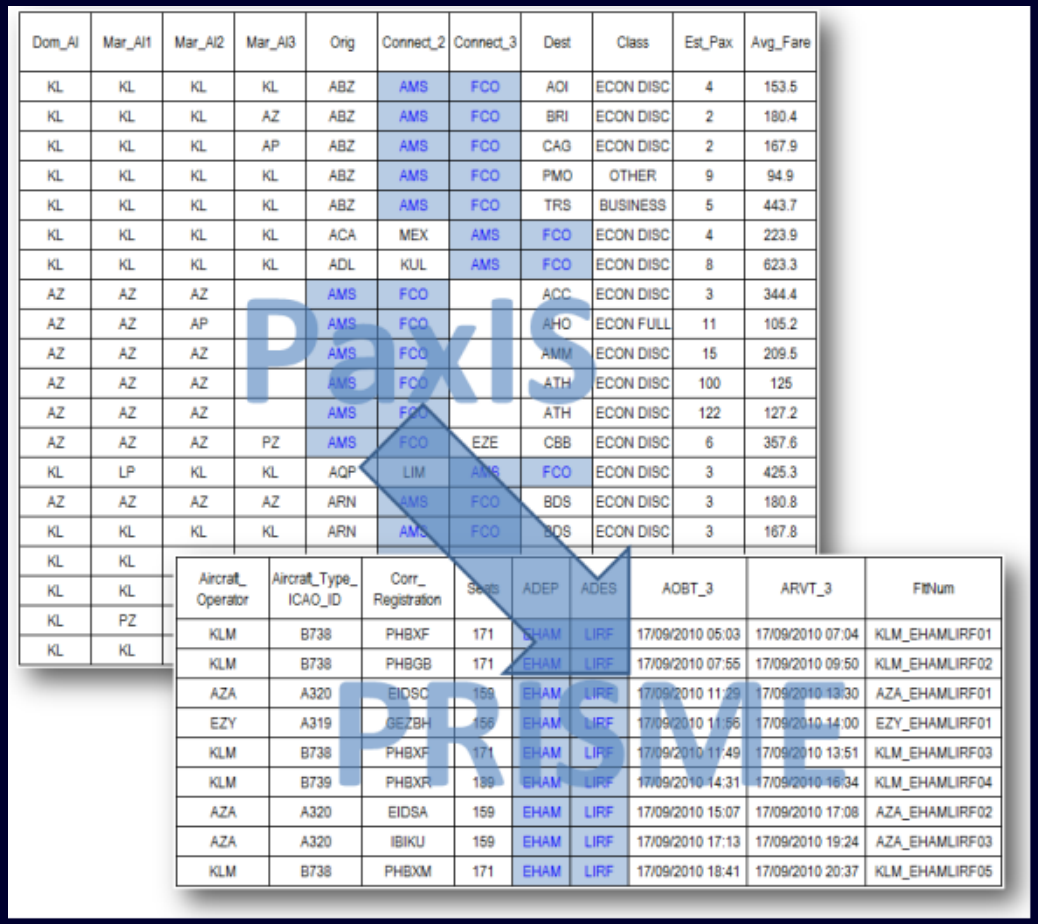
The POEM model

- structure and rules

Structure and rules

- Gate-to-gate aircraft rules; pax connection rules
- Varying levels of fidelity, for example:
- Rule 23: en-route (some recovery, 5 min residual, wind)
- Rule 33: passenger reaccommodation
  - trigger: pax late at gate (a/c not wait); cancellation; (*denied boarding)*
  - Regulation 261; IATA (involuntary rerouting & proration rules)
  - aircraft seat configuration data used with routing sub-rules
  - passenger prioritisation sub-rules (alliances, ticket flexibility, ties)
  - passenger hard and soft costs
  - multiple sources, including airline input and airline review
- Based on a nominal day (with optional disturbance)
- First such simulation of its kind

Structure and rules

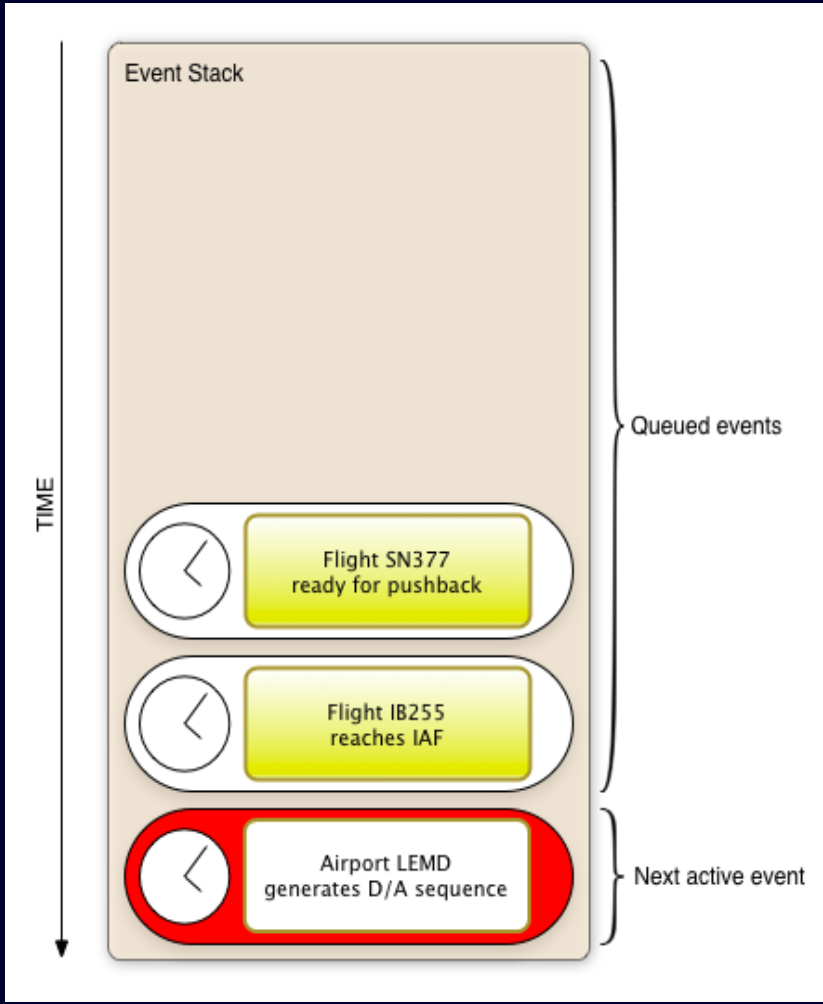


Dom_Al	Mar_Al1	Mar_Al2	Mar_Al3	Orig	Connect_2	Connect_3	Dest	Class	Est_Pax	Avg_Fare
KL	KL	KL	KL	ABZ	AMS	FCO	AOI	ECON DISC	4	153.5
KL	KL	KL	AZ	ABZ	AMS	FCO	BRI	ECON DISC	2	180.4
KL	KL	KL	AP	ABZ	AMS	FCO	CAG	ECON DISC	2	167.9
KL	KL	KL	KL	ABZ	AMS	FCO	PMO	OTHER	9	94.9
KL	KL	KL	KL	ABZ	AMS	FCO	TRS	BUSINESS	5	443.7
KL	KL	KL	KL	ACA	MEX	AMS	FCO	ECON DISC	4	223.9
KL	KL	KL	KL	ADL	KUL	AMS	FCO	ECON DISC	8	623.3
AZ	AZ	AZ		AMS	FCO		ACC	ECON DISC	3	344.4
AZ	AZ	AP		AMS	FCO		AHO	ECON FULL	11	105.2
AZ	AZ	AZ		AMS	FCO		AMM	ECON DISC	15	209.5
AZ	AZ	AZ		AMS	FCO		ATH	ECON DISC	100	125
AZ	AZ	AZ		AMS	FCO		ATH	ECON DISC	122	127.2
AZ	AZ	AZ	PZ	AMS	FCO	EZE	CBB	ECON DISC	6	357.6
KL	LP	KL	KL	AQP	LIM	AMS	FCO	ECON DISC	3	425.3
AZ	AZ	AZ	AZ	ARN	AMS	FCO	BDS	ECON DISC	3	180.8
KL	KL	KL	KL	ARN	AMS	FCO	BDS	ECON DISC	3	167.8
KL	KL									
KL	KL									
KL	PZ									
KL	KL									

Aircraft_ Operator	Aircraft_Type_ ICAO_ID	Corr_ Registration	Seats	ADEP	ADES	AOBT_3	ARVT_3	FltNum
KLM	B738	PHBXF	171	EHAM	LIRF	17/09/2010 05:03	17/09/2010 07:04	KLM_EHAMLIRF01
KLM	B738	PHBGB	171	EHAM	LIRF	17/09/2010 07:55	17/09/2010 09:50	KLM_EHAMLIRF02
AZA	A320	EIDSC	159	EHAM	LIRF	17/09/2010 11:29	17/09/2010 13:30	AZA_EHAMLIRF01
EZY	A319	GEZBH	156	EHAM	LIRF	17/09/2010 11:56	17/09/2010 14:00	EZY_EHAMLIRF01
KLM	B738	PHBXF	171	EHAM	LIRF	17/09/2010 11:49	17/09/2010 13:51	KLM_EHAMLIRF03
KLM	B739	PHBXR	189	EHAM	LIRF	17/09/2010 14:31	17/09/2010 16:34	KLM_EHAMLIRF04
AZA	A320	EIDSA	159	EHAM	LIRF	17/09/2010 15:07	17/09/2010 17:08	AZA_EHAMLIRF02
AZA	A320	IBIKU	159	EHAM	LIRF	17/09/2010 17:13	17/09/2010 19:24	AZA_EHAMLIRF03
KLM	B738	PHBXM	171	EHAM	LIRF	17/09/2010 18:41	17/09/2010 20:37	KLM_EHAMLIRF05

- aggregated PaxIS (IATA ticket) pax data allocated onto individual flights (PRISME traffic data)
- assignment algorithms respecting aircraft seat configurations and load factor targets
- full pax itineraries built respecting MCTs and published schedules
- 200 + 50 airports
- 30 000 flights
- 2.5 million pax
- 150 000 routings

Structure and rules



- event-driven: event stack, ordered sequence of events, each with a stamp
- dynamic tracking of costs for each a/c & passenger
- pre-computed cost functions: recursive (from end of day backwards along propagation tree); discrete (dly: 0, 5, 10, …)
- single-processor: 25-50 minutes to run one day
- cloud-computing platform: approximately 2 minutes

Structure and rules

Type, and level	Designator	Summary description
No-scenario, 0	S_0	No-scenario baselines (reproduces historical operations for baseline traffic day)
ANSP, 1	N_1	Prioritisation of inbound flights based on simple passenger numbers
ANSP, 2	N_2	Inbound flights arriving more than 15 minutes late are prioritised based on the number of onward flights delayed by inbound connecting passengers
AO, 1	A_1	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
AO, 2	A_2	Departure times *and* arrival sequences based on delay costs – A_1 is implemented *and* flights are independently arrival-managed based on delay cost
Policy, 1	P_1	Passengers are reaccommodated based on prioritisation by final arrival delay, instead of by ticket type, but preserving interlining hierarchies
Policy, 2	P_2	Passengers are reaccommodated based on prioritisation by final arrival delay, regardless of ticket type, and also relaxing all interlining hierarchies

The POEM model

- key results

Key results

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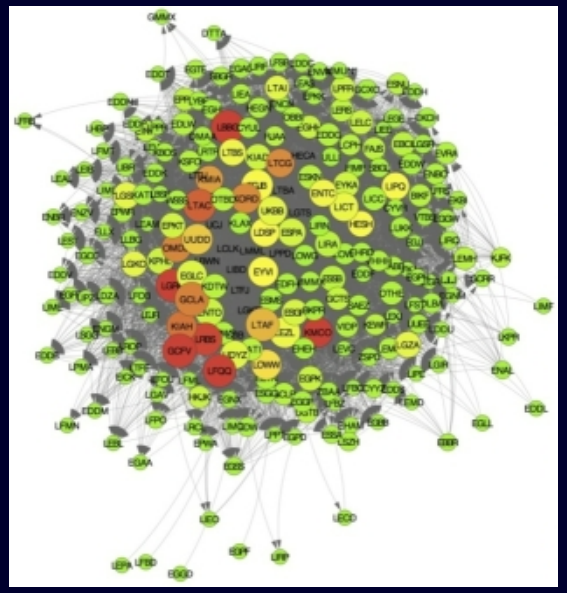
Key results



- Cost-minimising aircraft wait rules (A_1)
  - ↓ €39 avg. cost / flight
  - ↓ 9.8 mins avg. arr. / delayed pax
  - ↑ 2% reactionary (focus)

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

Where next?

- with the tool

Where next?

- Live model, on-going developments such as:
  - fidelity of various rules (flexible, event-driven; + CO_2?)
  - 2014 traffic with new costs; GDS integration; D2D context
- Exploring further use of valuable new metrics
  - passenger-centric; in context SES RP3 (2020 – 2024)?
  - increased focus on cost resilience
- Policy evaluation
  - e.g. Regulation 261; 'exploratory' policies
- Increased AO-level focus and software integration
  - strategic planning, trending context (e.g. a/c sizes & LFs)
- Parallel SESAR ConOps developments
  - e.g. UDPP (costs) and A-CDM (pax connectivities)

Where next?

- funded opportunities from SESAR

Funded opportunities from SESAR

- Horizon 2020 (EC) call, by 25 June 2015, 11 topics open:
  - 01: Automation
  - 02: Data science
  - 03: Information management
  - 04: Environment and meteorology
  - 05: Economics and legal change
  - 06: High performing airport operations
  - 07: Separation management
  - 08: CNS
  - 09: TBO
  - 10: ATM architecture
  - 11: ATM performance

WA1
'outreach'
≤ €0.6m each
TRL 1 (/2 OK)
(basic principles)

WA2
'applications-oriented'
≤ €1.0m each
TRL 1-2
(technology concept formulated)

Funded opportunities from SESAR

- Budget for this call: €20.6m (30-50 projects); 1 stage
- Outcome: 25NOV15; start: 25FEB16; duration ≤ 24 months
- Airline/industry funding = 100% (*full* salary) + 25% (o/h)
- *n* person days per month => *n* man-months overall
  - or could participate on an advisory/design Board

- Examples of some topics we're exploring:
  - (1) Optimising city-pair trajectories
  - (2) Enhanced ash cloud forecasting
  - (3) Improved cost resilience for schedules
  - … and A-CDM?

Funded opportunities from SESAR

(1) Optimising city-pair trajectories

- defining optimal European trajectories (fuel burn, cost of time, emissions costs) as driven by airline business models
- taking account of traffic and sector loads, disruptions,
- weather (LVP, holding, etc.) and time of day
- using ‘flown’ data (ALL_FT+, > 1GB/day), BADA + AO data

- Added value
  - big data architectures and specialist mining
  - data expertise: ALL_FT+, METAR, NEST, SWIM; BADA emissions
  - benchmarking across airlines, routes, airspaces; for whole year

Funded opportunities from SESAR

(2) Enhanced ash cloud forecasting

- enhanced post-processing and visualisation of forecasts
- for periods of 30/60 minutes (c.f. current 6 hours)
- includes forecast impacts on selected airports

- Added value
  - visualisation tool integrates forecast with flight plans (in any format) and with engine ingestion impacts
  - takes account of individual Safety Risk Assessment strategies (vary widely across airlines)
  - integrated with engine maintenance cycles; strategic preparedness

Funded opportunities from SESAR

(3) Improved cost resilience for schedules

- conflicting market forces: AO business models and regulatory change
  - e.g. pax Regulation 261 (extended scope and enforcement)
  - SES mandates, direct and indirect (e.g. route charges) effects
- fully monetised (e.g. pax *arrival* delay & compensation)
- decision support, e.g. cancellation or long delay?

] bottom -line impacts

- Added value
  - better alignment (cost resilience) between schedule and operations
  - considers multiple dependencies: pax, ANSPs, airports, emissions
  - reduces risk of unforeseen change: better business reactivity

Where next?

- challenges for A-CDM

Challenges for A-CDM

- SESAR 2015 Work Programme focuses on PCP alignment, targets re. Operational Focus Area 'Airports Operations Mgt':
  - connect TOBT with pax wait / no-wait decisions; better connect landside info with Airport Operations Plan
  - integrate MET data in management of adverse weather & DCB
  - validate interfaces between airport ops centres & stakeholder operational units; validate requirements re. decision support
  - validate use of a de-icing management tool within A-CDM context
- SESAR ER Call: "High performing airport operations" (#6)
  - new technologies for improved situational awareness for (remote) tower controllers (e.g. cameras and sensors)
- Inbound airport flows currently FPFS only
- Downstream (network) effects of DCB / A-CDM

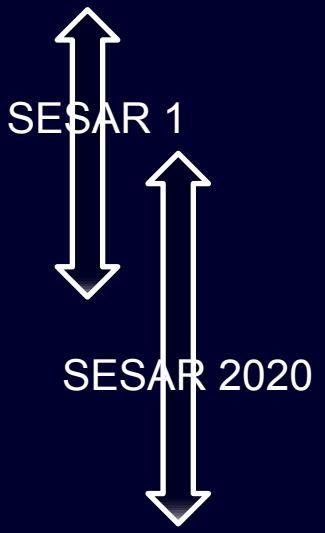
Thank you

airspace-research@westminster.ac.uk

Stand-bys

SESAR 2020

- 2015: first SESAR 2020 projects launch (2016: some SESAR 1 overlap)
  - Step 1: Time-based operations
  - (focus on flight efficiency, predictability and environment)
  - Step 2: Trajectory-based operations
  - (capacity, 4D trajectory optimisation, SWIM)
  - Step 3: Performance-based operations
  - (high-performance, integrated, network-centric, collaborative,
  - seamless air/ground system)



- Runs to 2024, funded under Horizon 2020
  - Exploratory Research (builds on WP-E; EUR 85m; purely EU funds)
  - Applied Research & Pre-Industrial Development (EUR 1200m)
  - Large Scale Demonstrations (EUR 300m)

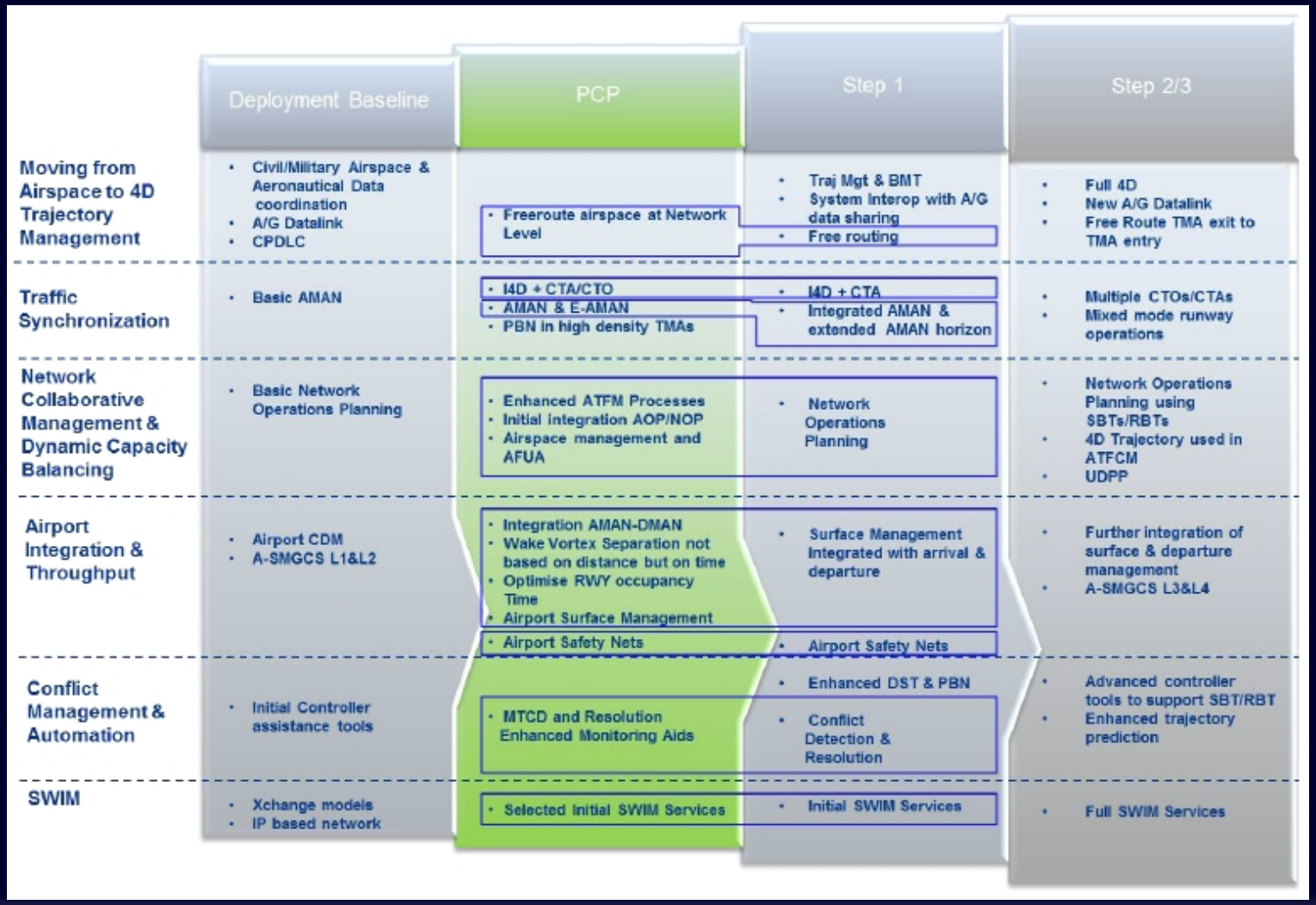
TRL 1 and 2

- TRL 1: Basic principles observed and reported
  - Exploring the transition from scientific research to applied research by bringing together a wide range of stakeholders to investigate the essential characteristics and behaviours of applications, systems and architectures. Descriptive tools are mathematical formulations or algorithms.
- TRL 2: Technology concept and/or application formulated (applied research)
  - Theory and scientific principles are focused on very specific application area(s) to perform the analysis to define the concept. Characteristics of the application are described. Analytical tools are developed for simulation or analysis of the application.

Pilot Common Project

- Commission's framework supporting MP implementation
- 'Common projects' to deploy proven ATM functionalities (AFs)
  - AF1: extended arrival management and PBN in high density TMAs
  - AF2: airport integration and throughput
  - AF3: flexible airspace management and free routes
  - AF4: network collaborative management
  - AF5: initial SWIM
  - AF6: initial trajectory information sharing
- PCP first set technical/operational changes
- To be implemented 2014-2024; details:
  - SJU Annual Work Programme
  - Implementing Regulation (716/2014, 27JUN14) defines mandatory AFs

Pilot Common Project



Simulation & scenarios

Designator	Rule 13 Wait for boarding	Rule 26 Airborne arrival management	Rule 33 Passenger reaccommodation
N_1		●	
N_2		●	
A_1	●		
A_2	= A_1	●	
P_1			●
P_2			●

Core metric	Units	N_1 & N_2	P_1	P_2	A_1
		Inbound prioritisation based on: simple pax numbers, or on onward flights delayed	Passenger reaccommodated based on delay at final destination … … preserving interlining hierarchies	… **relaxing interlining hierarchies**	Departures times based on **cost minimisation** (& consideration of ATFM delay)
Flight departure delay	mins / flight	no significant changes in current flight-centric metrics: stresses need for passenger-centric metrics			
Flight arrival delay	mins / flight				
Departure delay of departure-delayed flights	mins / flight				
Arrival delay of arrival-delayed flights	mins / flight				
Pax departure delay	mins / pax	no significant changes under simple inbound scenarios driven by passenger numbers, or by numbers of delayed onward flights	revised passenger re-booking rules produce only weak improvements whilst current airline interlining rules are preserved, c.f. →	=	+0.4
Pax arrival delay	mins / pax			-0.4	-1.6
Departure delay of departure-delayed pax	mins / pax			=	=
Arrival delay of arrival-delayed pax	mins / pax			-2.2	-9.8
Passenger value of time	Euros / pax			-0.2	-0.7
Non-passenger costs	Euros / flight			=	=
Per-flight pax hard cost	Euros / flight			+26	-40
Per-flight pax soft cost	Euros / flight			=	=
Total flight cost	Euros / flight			+26	-39
Total flight cost per minute of departure delay	Euros / min			=	-7.8
Reactionary delay ratio	ratio			49%	51%

Simulation & scenarios

[…](17-Sep-2010 12:25:00) 47 out of 49 of pax (95.92 pct.) of DLH_EDDLEGBB02:15877 were ready, flight over 80 pct. occupancy, no more delay added

(17-Sep-2010 12:25:00) Total cost of flight DLH_EDDLEGBB02:15877 departing at 17-Sep-2010 12:25:00 now estimated at 127.15 euros

(17-Sep-2010 12:25:00) No further pax delay will be introduced, thus flight DLH_EDDLEGBB02:15877 is now pushback ready, reaccommodating connecting pax

(17-Sep-2010 12:25:00) Pax group DLH1815:37550 of 2 inflex pax coming from DLH_EDDHEDDL06:12246 to EGBB did not make it to DLH_EDDLEGBB02:15877 (no more connections afterwards) and need to be reaccommodated

(17-Sep-2010 12:25:00) 2 inflex pax of group DLH1815:37550 of DLH_EDDHEDDL06:12246 that missed DLH_EDDLEGBB02:15877 were successfully reaccommodated in DLH_EDDLEGBB03:23396 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_EDDLEGBB02:15877 were left behind and all of them were successfully reaccommodated

(17-Sep-2010 12:25:00) Flight SAS_ENKBENGM03:15843 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_ENKBENGM03:15843 connecting with another flight afterwards (SAS3310:87574, SAS3311:87575, SAS3312:87576, SAS3313:87577, SAS3314, […] (KSU-OSL)

Hierarchy of interlining

Carrier type	Ticket type	Rebooking onto next available flight according to departure delay of:		
		up to 2 hours	2 – 5 hours	> 5 hours
full-service	flexible (first/bus.)	any carrier	any carrier	any carrier
full-service	business inflexible	booked/alliance only	any carrier	any carrier
full-service	all other tickets	booked/alliance only	booked/alliance only	any carrier
all other	all tickets	booked carrier only	booked carrier only	booked carrier only

- Rule 33 (sub-rules)
  - most airlines will try to rebook onto their own flights first
  - if LH wants to rebook onto LH1234, no other AO may claim seat
  - on reaccommodation, fare of remaining legs transferred to new carrier (if applies), according to IATA rules

Introducing the business trajectory

- The ‘Business (4D) Trajectory’
- Negotiated ‘contract’ with time constraints (hence 4D)
- Shared Business Trajectory (SBT)
  - Firstly, a trajectory is negotiated which represents the business intentions of the airline and takes account of Air Navigation Service Provider, ATFM and airport constraints
- Reference Business Trajectory (RBT)
  - Negotiation complete: trajectory which airline agrees to fly and ANSP + airport agree to provide; c.f. current practice, from both providers and users, of pre-tactical and tactical changes: new concept designed to minimise changes to trajectories & achieve ‘best business outcome’ for all users
- A key business outcome is reduction of delay

Complexity science

- Not one theory; system of systems – usually a network
  - multiple components, non-linear dynamics: can't predict
  - non-analytical models, e.g. agent-based
  - usually need to take uncertainty into account
- Emergent behaviour, e.g. delay propagation
- ATM = complex socio-technical system
- How can complexity science contribute?
  - user-defined nodes in topological networks
  - existing metrics such as centralities (causality)
  - existing methods such as community detection & percolation
- Complementary approach
  - classical and complexity