The cost of delay

Cook, A.J.

Presented at the EUROCONTROL Agency Research Team, Ecole Nationale de l'Aviation Civile, Toulouse, 24 March 2016.

The cost of delay

Dr Andrew Cook
Principal Research Fellow
University of Westminster

Overview

- A brief history
- Methodology and refinements
- Trends and headlines
- Users and example SESAR projects
- Where next?

A brief history

A brief history

- 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 …

Acknowledgements

The authors would like to thank the following for data provision and advice generously offered during the course of this research. We would especially like to thank the airlines who made particular, and often extensive, efforts to provide the detailed financial and operational data required as inputs to this Study.

Air France

Airbus Industrie

Austrian (Airlines)

Aviation Industry Press

Boeing Commercial Aircraft

Britannia Airways

British Airways

Condor Flugdienst

Cranfield College of Aeronautics

CSA Czech Airlines

Deutsche Flugsicherung

EasyJet

Four (anonymous) aircraft lessors

Four anonymous handling agents

IATA (Geneva & London)

Iberia

KLM Royal Dutch Airlines

Lido GmbH

Lufthansa

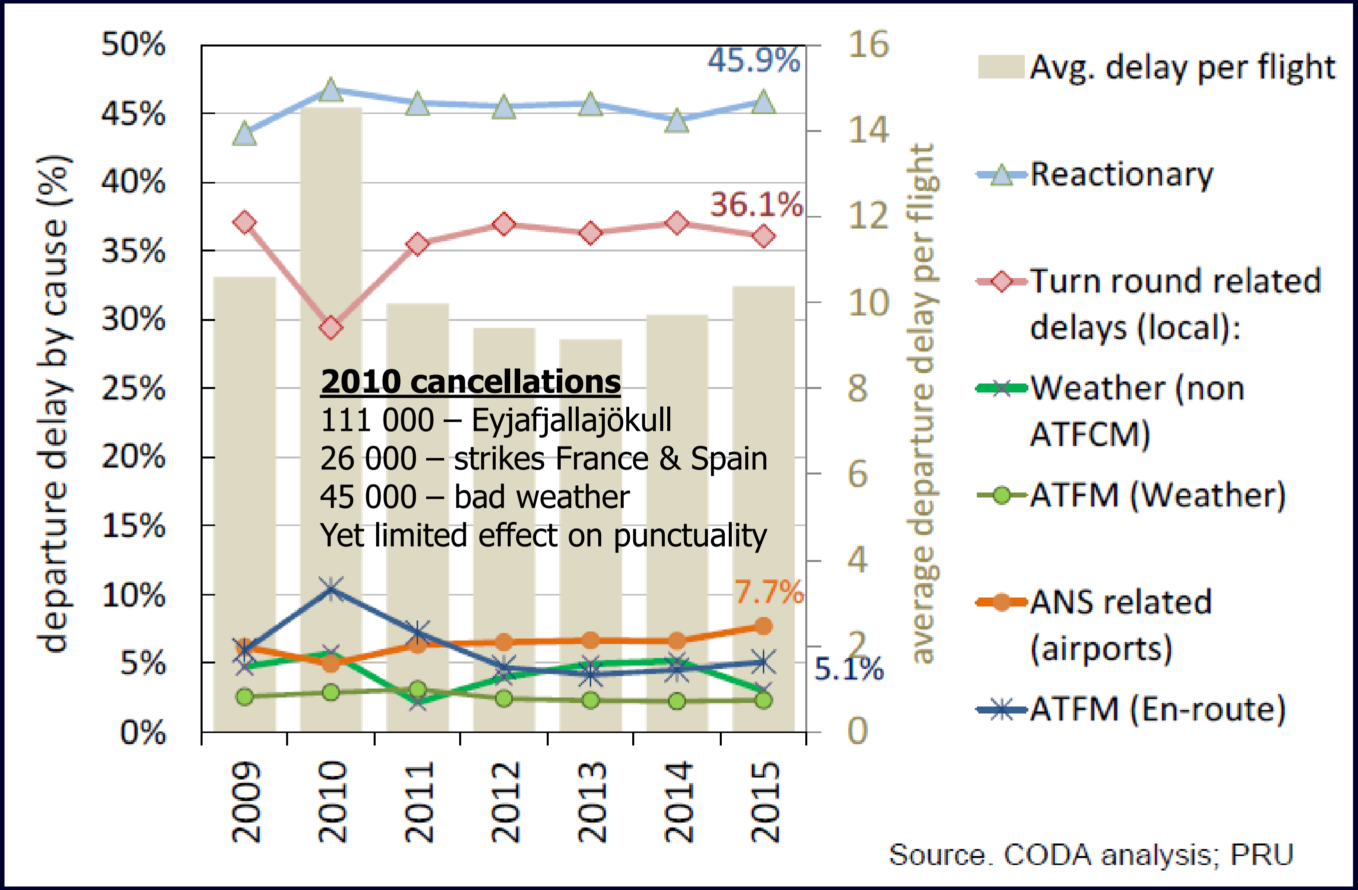
The Airline Monitor

The Federal Aviation Authority

Various airport charges' offices

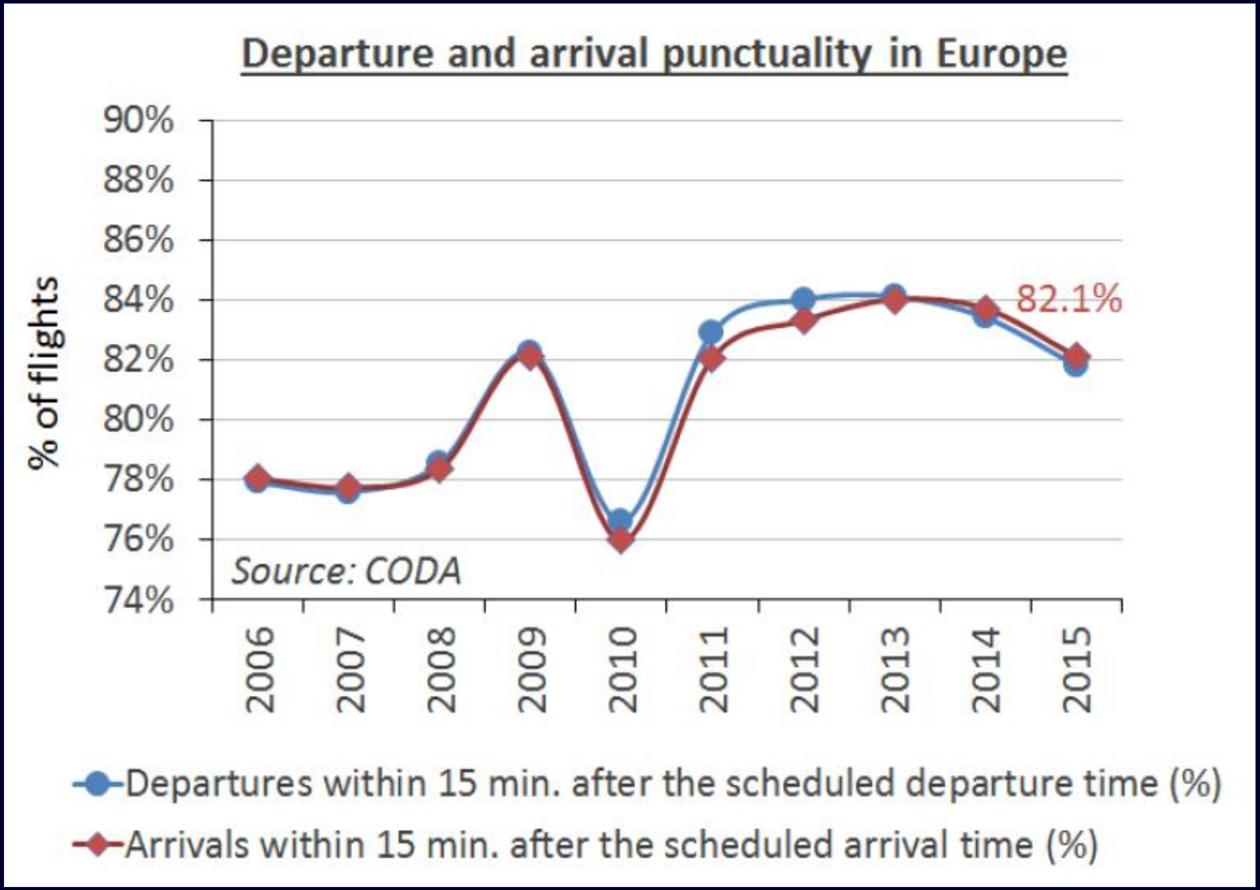
The authors are also heavily indebted to continuous technical support and advice from PRU at all stages of this Study, and to Mr Vittorio Pimpinelli for so ably chairing a valuable workshop held in Brussels to review Edition 2 of this Report.

A brief history



Sources: PRR 2010, 2015 (draft)

A brief history



Source: PRR 2015 (draft)

A brief history

metric	2000	2015
IFR flights	8.4M	9.8M
% flights arr. > 15 mins late	27%	18%
turnaround delay	? 33%	36%
reactionary delay	39%	46%
ATFM/ANS delay	23%	13%

Sources: PRR 2000, 2015 (draft)

NB1. SESAR target for 2020: > 95% of flights arrival delay ≤ 3 mins
(*Performance Target* and *Target Concept*) other 5%: average delay < 10 mins

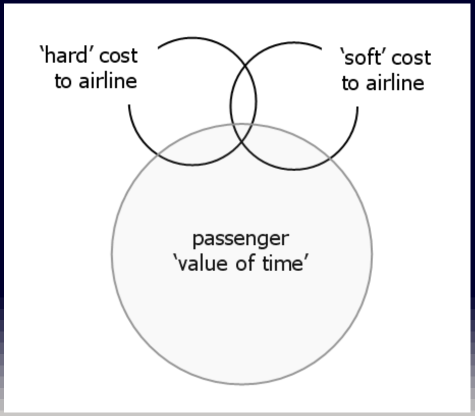
NB2. Traffic in 2008: 10.1M (peak, start of slowdown and fall)

A brief history

- 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

A brief history

- 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)



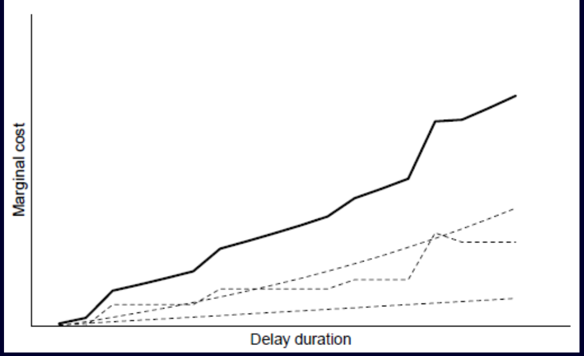
A brief history

- Novel features of 2004 report
  - "ground" and "airborne" costs of delay
    - taxi and arrival management in method but subsumed in output
  - "short" and "long" delay types
    - 15-minute and 65-minute delays taken as models
  - by aircraft type (Annex N) and by cost scenario (low, base, high)
    - B733, B734, B735, B738, B752, A319, A320, A321, AT43, AT72; B744, B763
  - other public domain European costs, also by aircraft type
    - fuel burn tables and BHDOCs (industry sourced/verified)

A brief history

- Non-linear models, things of the future …
  - delay cost by duration

Figure 2-6: Illustration of a compound function



  - reactionary delay models

Table 2-22: Reactionary delay multipliers

Duration of delay	Reactionary delay multiplier
15 minutes	1.05
65 minutes	1.20

Methodology and refinements

Methodology and refinements

element	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	'hard' & 'soft' (not internalised costs)
ground handling	aircraft and passengers – penalty if late / delayed on gate
airport charges	various aeronautical charging manuals and policies consulted
en-route ATC charges	based on GCD entry/exit – requires significant re-route due delay
CO_2	considered allocated permits and CO_2 price; small % fuel variation

Methodology and refinements

element	strategic	tactical
fleet	= *f* (service hours)	≠ *f* (utilisation) = 0
fuel	= (e.g. no hedging between phases)	
crew	unit	marginal (0 … full o/t)
maintenance	unit	marginal (e.g. fixed LTOs)
passenger	0	dominate, non-linear

Table 1-1: Airline operating costs and revenues

Non-operating items		Direct operating costs		Indirect operating costs	Operating revenue
Losses	**gains**	**variable**	**fixed**		
retirement of equipment or property, when depreciated (residual) values are not realised		*direct engineering costs:* - related to block hours and/or cycles - (e.g. spares, A-D checks)	*engineering overheads:* - fixed staff costs (unrelated to a/c utilisation) - maintenance administration [g]	-	-
interest paid on loans	interest received from deposits	a/c fuels: - fuel - oil [b]	a/c standing charges: - depreciation - rentals [c] / leases - insurance	-	-
losses from affiliated companies, subsidiaries and shareholdings	profits from affiliated companies, subsidiaries and shareholdings	- flight crew subsistence and bonuses - cabin crew subsistence and bonuses	- annual flight crew costs (fixed salaries, pensions etc unrelated to flying hours) + administration - annual cabin crew costs (fixed salaries, pensions etc unrelated to flying hours) + administration - amortisation of crew training costs [e]	-	-
miscellaneous losses from foreign exchange transactions, sales of shares	miscellaneous gains from foreign exchange transactions, sales of shares	*airport aeronautical charges* [a] - landing charge - airport parking/hangerage - (departing) pax charge - ground handling *en-route ATC* [a]	-	- station and ground expenses [d] - ground equipment, property, transport depreciation - ground staff	-
-	government subsidies	- pax delay compensation - pax meals/hotel expenses [f] - third-party pax handling	-	- passenger service staff - passenger accident / liability insurance	-
-	-	-	- amortisation of route development costs	- ticketing - agency commissions - sales - promotion	sales revenues: - AO own effort - from other AOs (e.g. flex tickets, off-loads)
-	-	-	-	- general admin	-

Footnotes

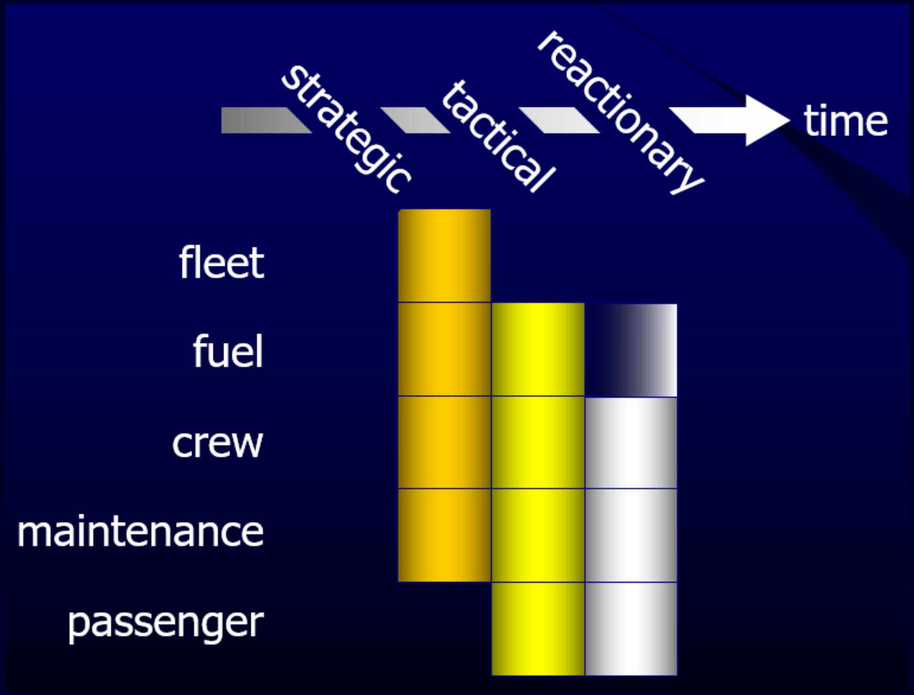
[a] classified by ICAO as an *indirect* operating cost (although few AOs adopt this classification)
[b] very small overall cost compared with fuel – not costed further in this Study
[c] high leasing levels will normally be associated with (very) low depreciation charges, as rental charges for leased a/c cover both depreciation and interest charges paid by lessor
[d] at outstations often includes maintenance, due to difficulties of cost separation
[e] may be considered as a direct operating cost, especially when not amortised
[f] for example if accommodation is provided for transit passengers
[g] often documented / categorised as "maintenance burden"

Table 2-7: Template for gate-to-gate cost calculations

cost allocation phase ►	direct @ ground A					direct airborne				incurred @ ground B			
OOOI sequence ►	- (IN) -		- OUT -			- OFF -				- ON -			- IN -
description ►	@ gate A		off-gate A			airborne				off-gate B			@ gate B
	GPU only	APU only	active taxi out	statnry ground	take-off roll	climb-out (to ToC)	en-route	arrival mngmnt	ToD to t'down	landing roll	statnry ground	active taxi in	
▼ cost element													
fuel		[val]	[val]	[val]		---	[val]	[val]	---		---	---	---
maintenance	[val]	[val]	[val]	[val]		---	[val]	[val]	---		---	---	---
flight crew salaries and expenses Cabin crew salaries and expenses	[val]	[val]	[val]	[val]		---	[val]	[val]	---		---	---	---
depreciation of flight equipment rental of flight equipment amortisation of flight equipment leases	[val]	[val]	[val]	[val]		---	[val]	[val]	---		---	---	---
flight equipment insurance	---	---	---	---		---	---	---	---		---	---	---
station expenses (ground & pax handling)	---	---											[val]
passenger service staff (terminal) ground equipment, property and staff	---	---	---	---			---	---			---	---	---
airport charges (e.g. landing)	[val]	[val]			[val]					[val]			[val]
en-route & approach air navgn charges						---	---	---	---				
all other pax costs	►	►	►	►	►	►	►	►	►	►	►	►	[val]
column totals	[val]	[val]	[val]	[val]	[val]		[val]	[val]		[val]			[val]
proportion of col. total allocated to phase	0.81	0.09	0.04	0.06	1		0.2/0.7	0.8/0.3		1	---	---	1
=> average cost per minute for phase			[val]					[val]			[val]		
avg cost per min <u>incl.</u> incurred costs @ B			[val]					[val]					

[val] => value to be calculated: see Annex J

Methodology and refinements



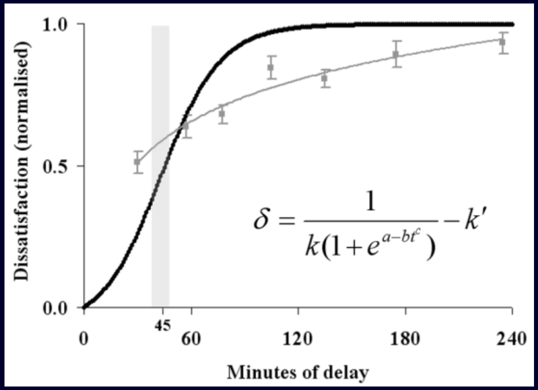
2004 ⇨ 2010

Methodology and refinements

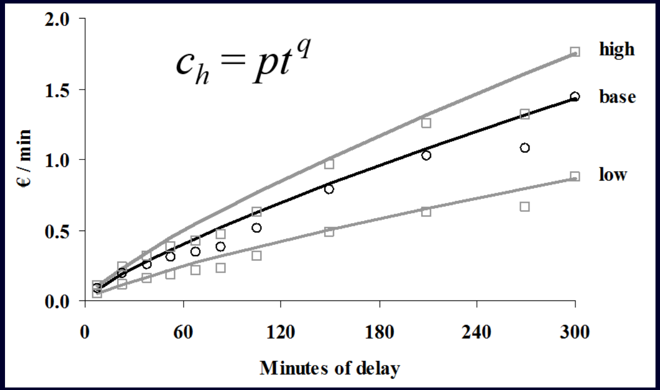
Cost element	2004	2010
Pax hard cost	Treated as zero for <15 minutes of delay	Major update - full cost curves (power curve) derived as function of primary delay
Pax soft cost	Treated as zero for <15 minutes of delay	Major update - full cost curves (logit curve) derived as function of primary delay; scalability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

Methodology and refinements

- Passenger costs modelling in 2010 (2nd edition)
  - originally Austrian + 'Airline Z' (very close), single average value
  - Regulation (EC) No 261/2004 (17 February 2005)
  - logit curve (soft), power curve (hard) – basic, but *f* (duration)



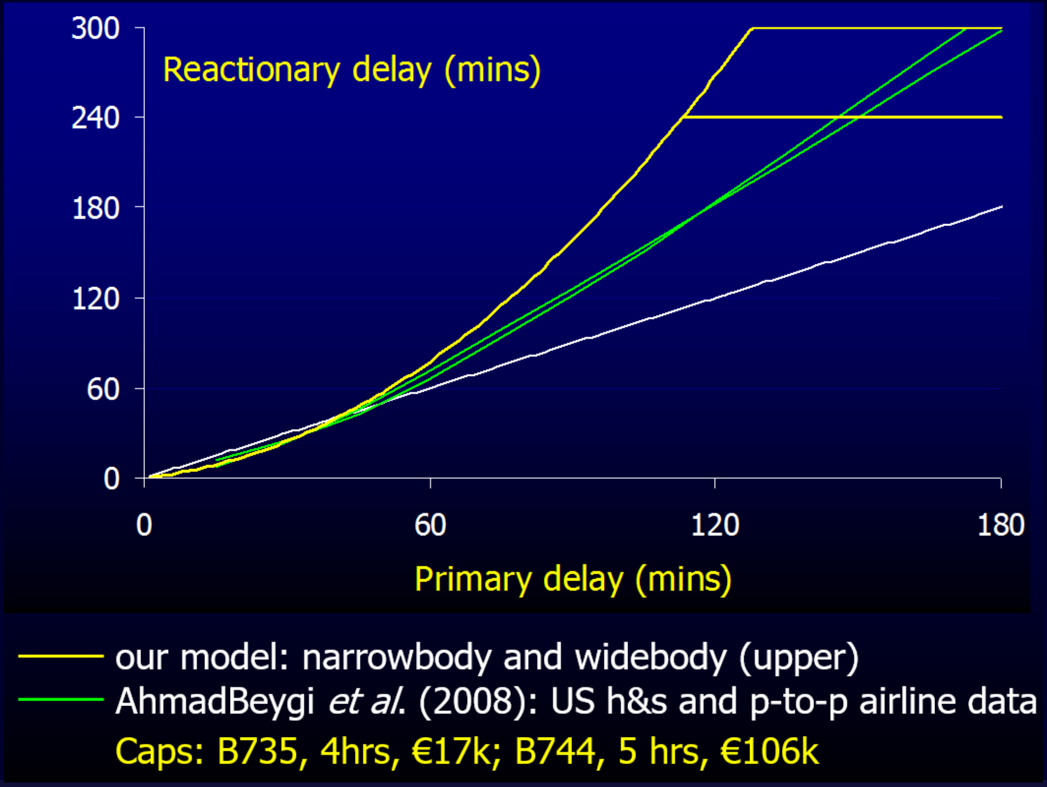
Airline passenger Kano satisfaction model, Wittmer and Laesser (2008).
In-house, bespoke surveys & airline models



Regulation 261 + airline policy.
Limited airline data & literature; care & reaccommodation model

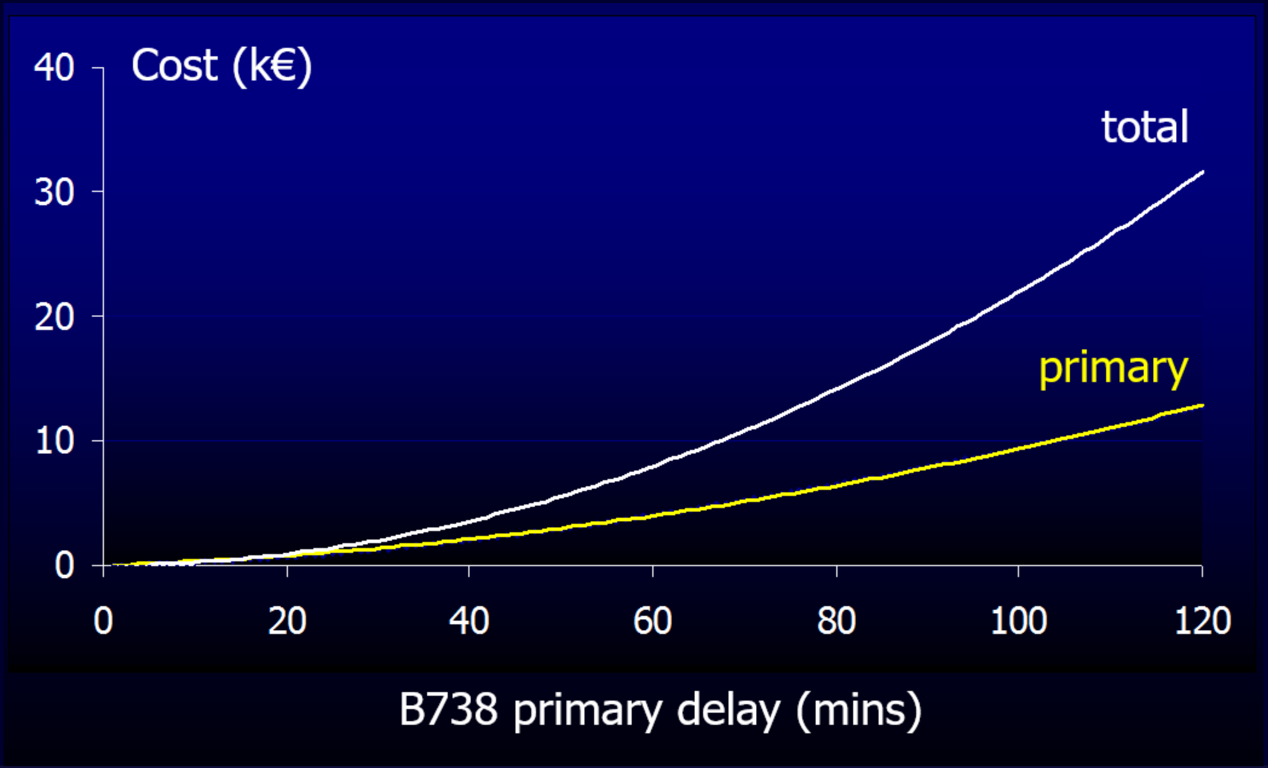
Methodology and refinements

- Reactionary costs modelling in 2010 (2nd edition)
  - per cost element; n/b & w/b; recovery; l/b/h … also *f* (duration)



Methodology and refinements

- Reactionary costs modelling in 2010 (2nd edition)
  - rotational & non-rot; at-gate; statistical c.f. explicit modelling



2010 ⇨ 2015

Methodology and refinements

- Major updates in 2015 (3rd edition) – 2014 basis; WP-E
  - 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
  - APU fuel added at-gate (average 25% running, base scenario)
  - 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%

Trends and headlines

Trends and headlines

- Difficult to establish consistent trends
  - crew and maintenance costs least volatile (from overall perspective)
  - fleet costs most dependent on particular a/c types
  - passenger costs to AO most dependent on legislation (later)
  - fuel prices most volatile
- Cost of fuel
  - Jet A1, into-plane; typical lag c.f. spot prices
  - price (EUR/kg): 0.80 (2014), 0.60 (2010), 0.31 (2004)
  - often separated-out by phase (e.g. for DCI)

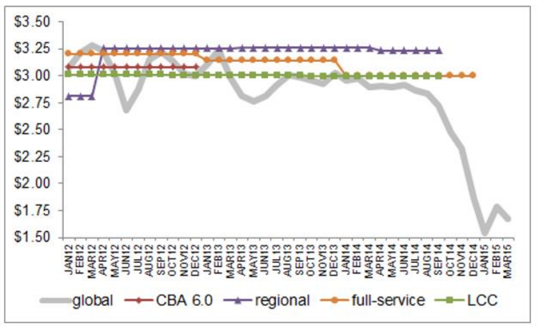


Figure 46. Average Jet A-1 fuel spot prices paid by airlines ($/US gallon)

Airline Business (etc.)

Trends and headlines

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

Table 30. European ATFM delay cost estimates

Factor	2014 value	2010 value
Average cost of delay of an ATFM-delayed aircraft	**1 970**	1 660
ATFM delay cost averaged over all flights	**103**	130
Network average cost of ATFM delay, per minute	**100**	CARE! 81

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.

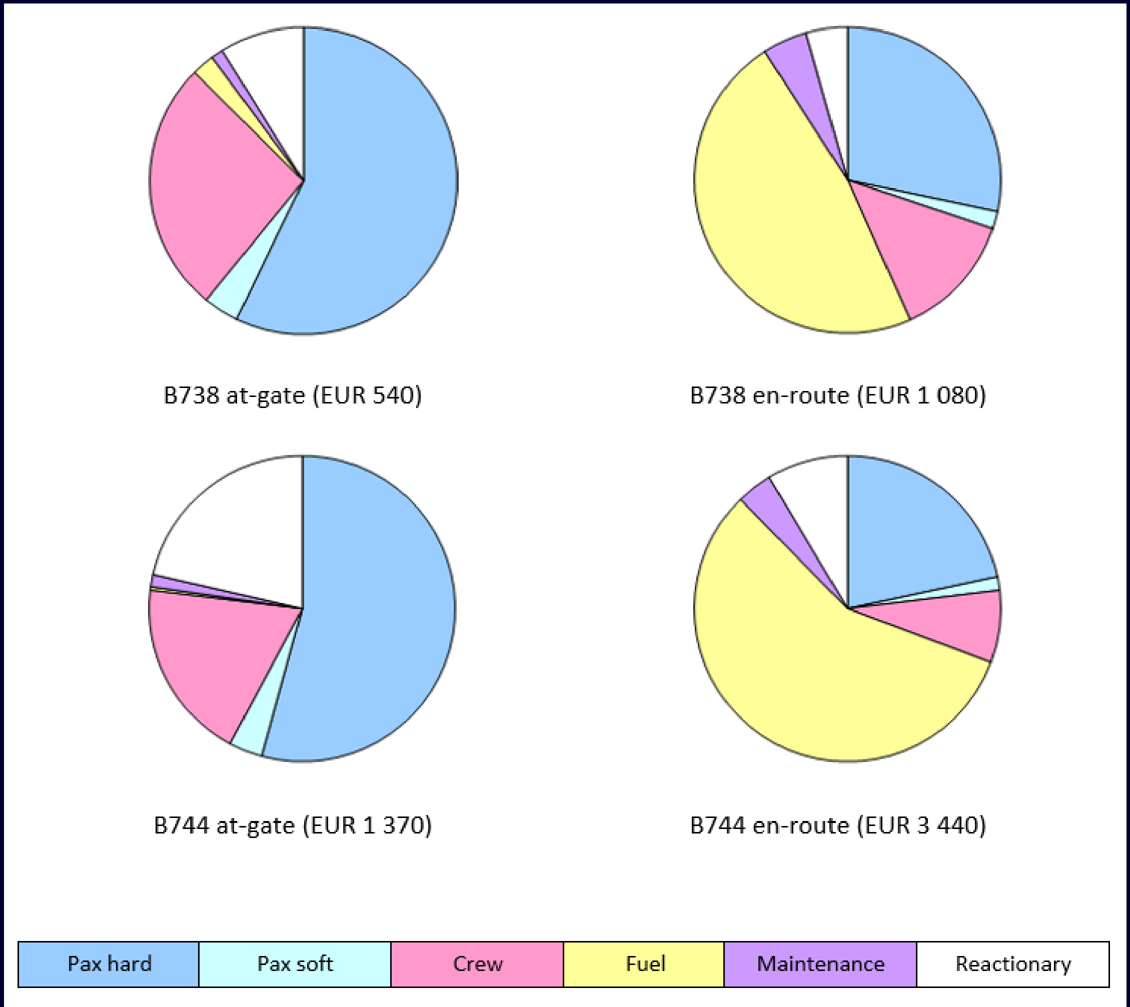
Trends and headlines

Table 26. AT-GATE / BASE / full tactical costs

Delay (mins)	5	15	30	60	90	120	180	240	300
B733	70	430	1 550	7 020	19 160	36 220	49 040	66 480	89 310
B734	80	480	1 740	7 930	21 690	40 960	55 340	74 780	100 040
B735	70	390	1 400	6 280	17 110	32 350	43 900	59 720	80 590
B738	90	540	1 940	8 860	24 270	45 750	61 740	83 220	110 920
B752	100	620	2 290	10 620	29 250	55 150	74 240	99 700	132 200
B763	170	900	3 200	14 780	39 960	85 300	121 880	152 860	191 990
B744	240	1 370	5 000	23 430	63 710	136 330	194 330	242 440	302 200
A319	70	440	1 600	7 320	20 040	37 850	51 240	69 420	93 180
A320	80	500	1 820	8 350	22 920	43 250	58 420	78 890	105 380
A321	100	580	2 160	10 010	27 580	51 990	70 060	94 250	125 240
AT43	30	180	610	2 610	6 960	13 290	18 550	26 360	37 610
AT72	40	240	820	3 600	9 690	18 430	25 380	35 350	49 210
DH8D	40	250	890	3 900	10 530	19 990	27 480	38 120	52 780
E190	60	320	1 150	5 140	13 970	26 440	36 060	49 420	67 340
A332	180	990	3 550	16 480	44 620	95 330	136 120	170 480	213 660

With reactionary costs.

Trends and headlines



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

Trends and headlines

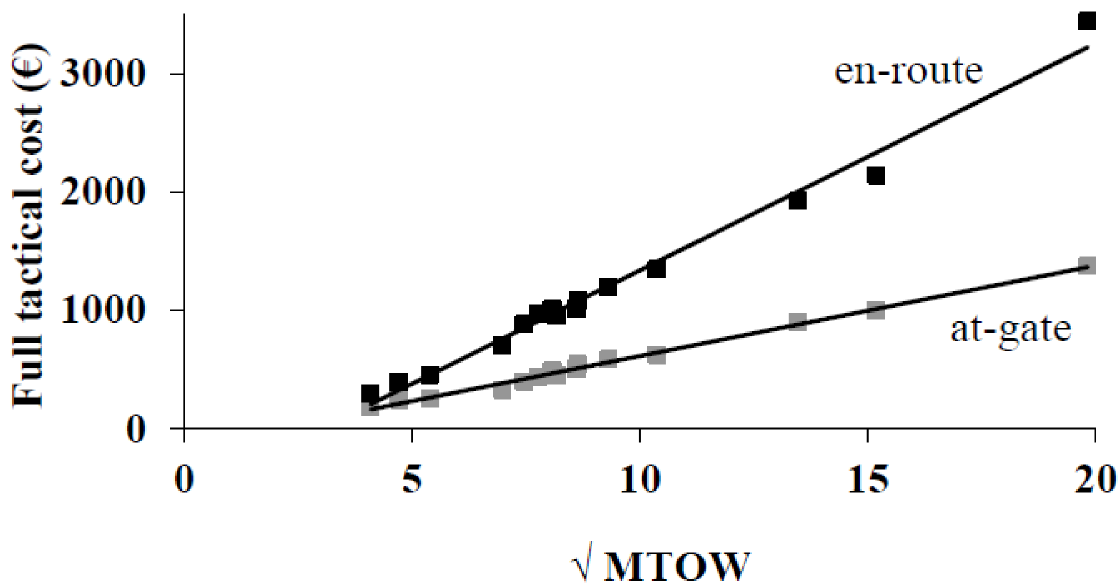


Figure J1. Full tactical cost as a function of √MTOW

Users and example SESAR projects

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)

Users and example SESAR projects

- SATURN project (SESAR WP-E; led by University of Trieste)
  - market-based demand-management mechanisms to redistribute air traffic in the European airspace, at the strategic level
  - SES Charging Regulation 391/2013 – "Modulation of charges"
    - modulation of en-route charges (peak & off-peak rates per ANSP)
    - whole European airspace modelled (30 000 flights; busy day in SEP14)
- Key results
  - peak pricing a viable option, respecting ANSP revenue neutrality
  - about 9% of sector-periods were heavily loaded (>90% utilisation) on test day; SATURN mechanisms reduced this to 5%
- Future work
  - exploring flexible capacity provision
  - improved AO choice determinants (incl. price elasticities)
  - extension to include AO tactical cost benefits

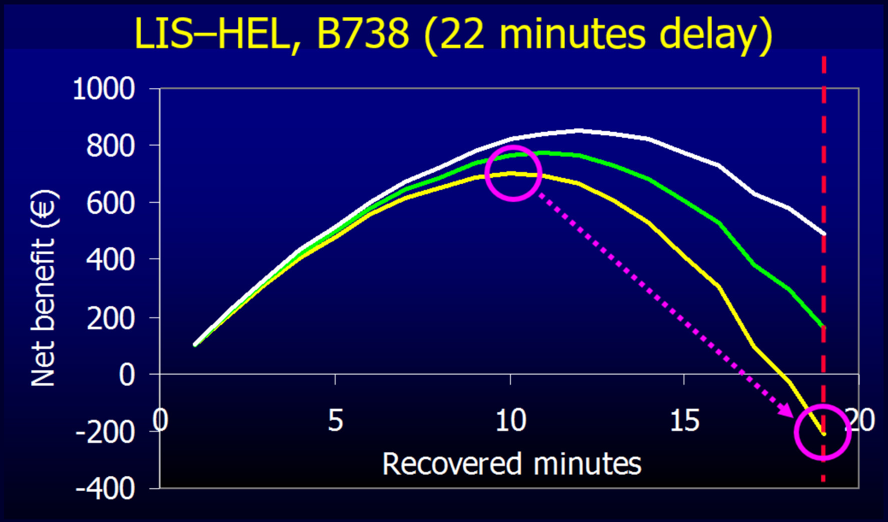
Users and example SESAR projects

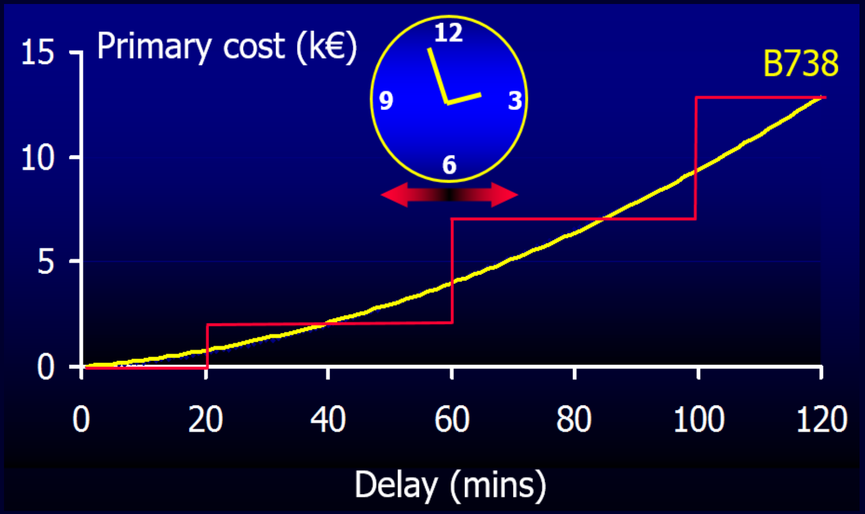
- ComplexityCosts project (SESAR WP-E)
  - comparative effectiveness of various mechanisms at increasing cost resilience under different types of disturbance
  - mechanisms (baseline and enhanced)
    - A-CDM; pax reaccommodation tools; DCI; increasing ATCO hours
  - disturbances (with background ATFM; local and disperse)
    - local airport weather; ATC strikes; ATC capacity (staffing)
  - differential stakeholder adoption by ANSP, AO & airport type
    - current, early adopter (baseline -> enhanced), follower (new uptake)

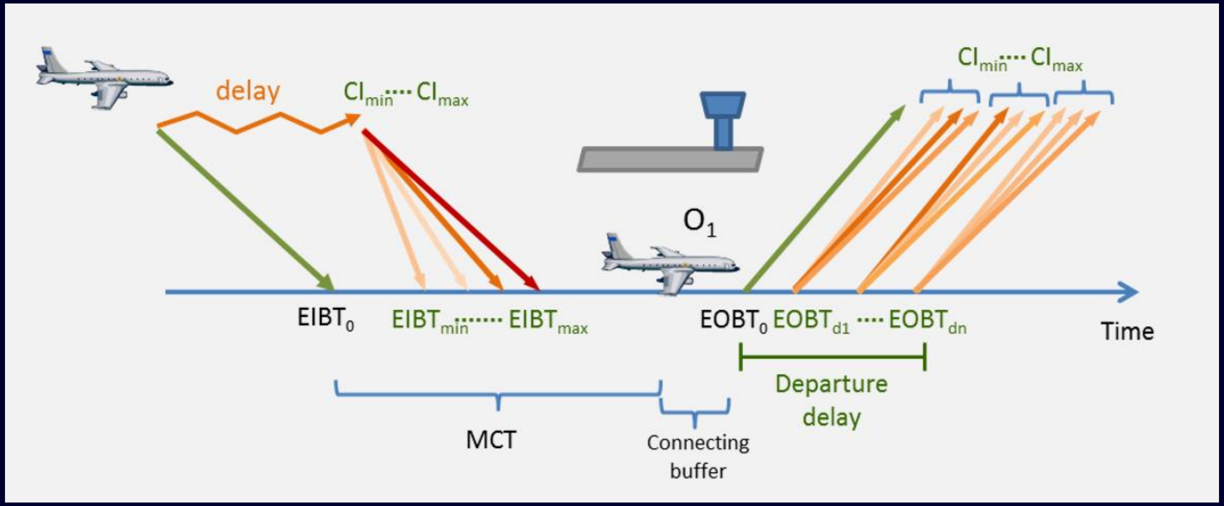
40

- Current work
  - stochastic, event-driven model: interacting elements & feedback
  - capture of complex dependencies often overlooked in trade-offs
  - airports: 200 ECAC + 50 external (month + busy day in SEP14)
  - full cost allocations to (>2.5M) passenger itineraries, and AO types
  - new resilience metrics – including strategic and tactical costs

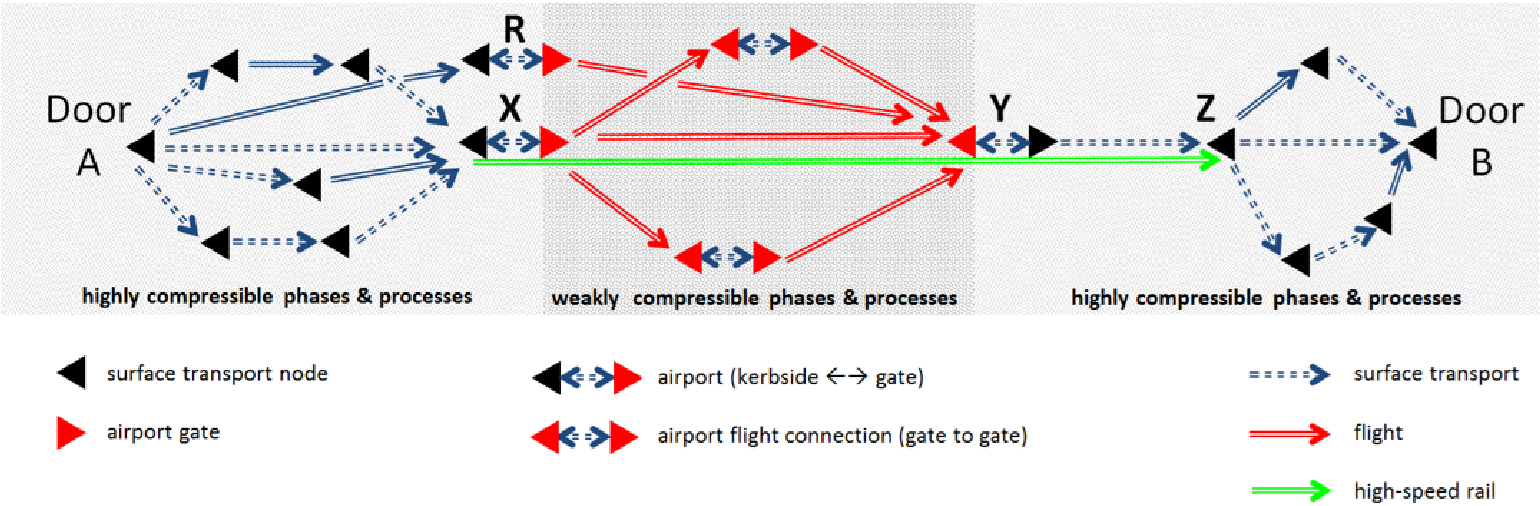
Where next?


LIS–HEL, B738 (22 minutes delay)
Net benefit (€)
1000
800
600
400
200
0
-200
-400
0
5
10
15
20
Recovered minutes


Primary cost (k€)
15
10
5
0
B738
12
3
6
9
0
20
40
60
80
100
120
Delay (mins)


delay
CI$_{min}$···· CI$_{max}$
CI$_{min}$···· CI$_{max}$
O$_1$
EIBT$_0$
EIBT$_{min}$······ EIBT$_{max}$
EOBT$_0$ EOBT$_{d1}$ ···· EOBT$_{dn}$
Time
Departure delay
MCT
Connecting buffer

Flightpath 2050 – 4 hours D2D for 90% of pax?



>> ***Multiple D2D pathways:*** some legs (= = =) are more compressible; regional / 2° options

>> ***Airport access, process and egress particularly compressible***

- road congestion; PT (priorities); interchange times / direct access; frequencies / capacities
- K2G (automation & smart systems): check-in (baggage); security / passport control; + MCTs

>> ***Gate-to-gate (G2G) performance relatively pretty good***

- 82% of arrivals within 15mins (buffers); e/r ATFM = 0.73 mins/flt; hor. e/r ineff = 4.7% (2015)

>> ***Compare 3h49 average CDG connections***

Where next?

- Further research needed
  - pax costs evaluation: Reg. 261 revision (e.g. 2 hours; 90 minutes)
  - metric integration (A-CDM; 4H D2D; RP3?): pax delay ≠ flight delay
  - reactionary delay (PRRs) and propagation; cancellation costs
  - *Standard Inputs for EUROCONTROL CBA* (etc.) – updated web tools
- Applications
  - integration with strategic and tactical tools
    - ANSP (rostering) and AO (scheduling and routing)
    - ground (e.g. Sabre; A-CDM) and airborne (e.g. PACE) tools
  - flight prioritisation mechanisms (e.g. UDPP)
  - EU policy/mobility evaluation, e.g. Reg. 261 and beyond … 4H D2D

Thank you

airspace-research@westminster.ac.uk

http://www.eurocontrol.int/publications/european-airline-delay-cost-reference-values