Why do we need improved models in ATM?

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Engage thematic challenge 4 workshop

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SESAR JOINT UNDERTAKING

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Why do we need improved models in ATM?
Overview

- Agents are not always fully ‘rational’
- Agents sometimes ‘bend’ the rules
- Demand management – current and potential
- Costs, charges and equity
- Initial challenges

Agents are not always fully ‘rational’

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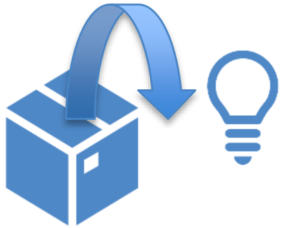
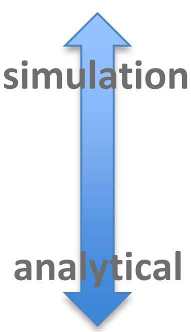


- **Agent**: both senses of a real stakeholder (often an airline, 'AU') and element of a model
    - "A person or thing that takes an active role or produces a specified effect"

      (OED, 2018)
    - "A computer programme, or part of a programme, that can be considered to act autonomously and that represents an individual, organisation [or other actor]"

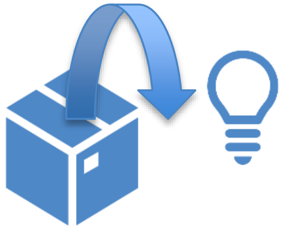
      (basic: e.g. omits explicit sensor capability and goals)

      (Gilbert, 2008)
- Modelling: often with a remit to improve **predictability**, e.g.:



    - agent-based modelling (ABM)
    - ABMS: focus on dynamics in environment over time; complex systems
    - machine learning (trajectory prediction; safety risks; runway throughput, ...)
    - 'classical' data reduction methods (e.g. principal components analysis)
    - stated-preference methods (conjoint analysis)

Agents are not always fully ‘rational’



- ‘Rational’: common sense, technical sense
  - “Based on or in accordance with reason or logic”

(OED, 2018)

  - “ [normative] ... logically consistent, as prescribed by the optimizing model at the heart of economic reasoning, sometimes called rational choice theory”

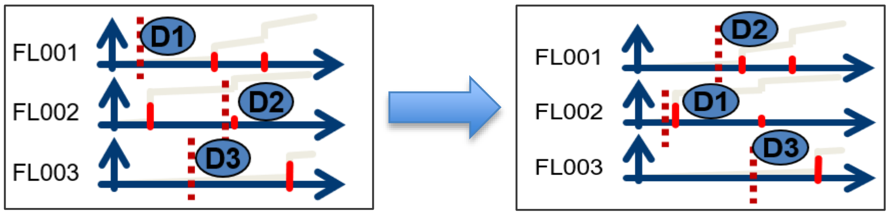
(Thaler RH, 2016)

- Expected utility theory: choices based on highest expected utility – how ‘***should***’ act
- Prospect theory: how (agents) ***actually*** act – *relative* change, loss / gain asymmetry
- Both model choice under uncertainty: does it matter which one we use?
- Are the errors random, or systematic? Can we invoke the ‘as if rational’ argument?
- Central to ATM is the agency of passengers, airlines ... humans not algorithms (so far!)

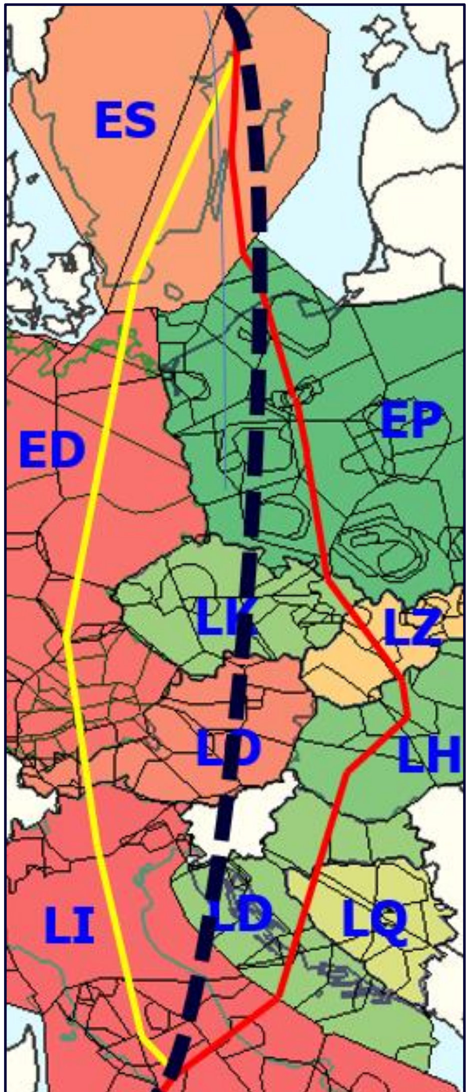
Agents are not always fully ‘rational’

Some ideas from prospect theory, worth considering in ATM? – (i) slot management

- **Loss aversion:** losses are worse (have more disutility) than gains are good (have utility)
  - e.g. avoiding a €1k slot delay is preferred to an (immediate) €1k ‘slot credit’
- **Endowment (inertia) effects:** a higher value is attributed to a good already owned
  - e.g. might pay as much to avoid CTOT + 15, as (CTOT + 15) + 15
- **Path dependencies:** the value of a good depends on the path of acquisition
  - e.g. ‘we protected this slot today after sacrificing ten flights last week, so there is no way we are going to trade it today’
- **Future discounting:** the value of a good depends on when it is consumed
  - e.g. one 30-minute slot improvement today is worth two identical improvements next week



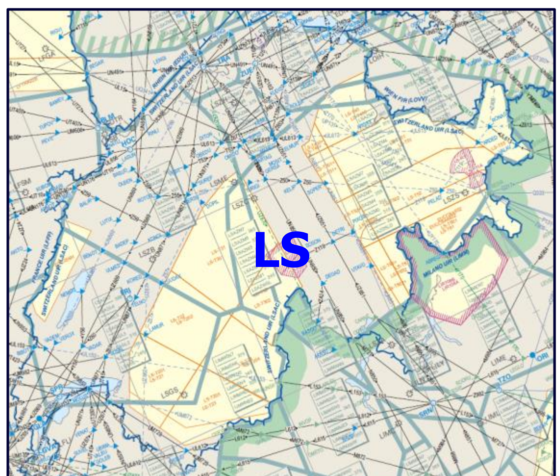
Agents are not always fully ‘rational’

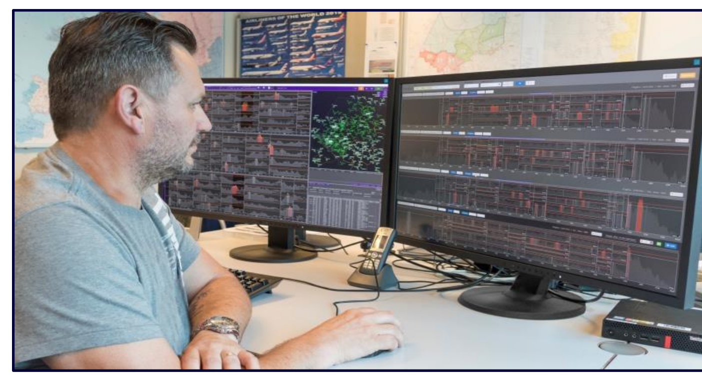


Some ideas from prospect theory, worth considering in ATM? – (ii) better forecasting for service providers

BDI

- Airline behaviour not always fully ‘rational’, e.g.
  - loss aversion (high weight) with delay *perception*
  - price elasticities with memory (inertia) effects
  - can lead to (macro) ‘culture’ effects (c.f. probabilistic)
  - c.f. micro (shift-related) effects – “Do we?!”
- Integration of (imperfect) learning?
- Scenario-based – worst-case capacity shortfalls, real issue ...





↑ Sector Opening Table Architect and Traffic Prediction Improvements software (big data and machine-learning initiatives at MUAC)

Agents sometimes ‘bend’ the rules

Agents sometimes ‘bend’ the rules

- ‘Gaming’ the system
  - serious issue in many markets
  - adds support for administrative systems (e.g. FPFS)
  - ATM not exempt, yet little research to date
  - may be *reduced* by ‘If...Then’ conditionality of smart contracts, and their ability to process secret data
  - smart contracts: digitally facilitate (*enforce*) a contract without the need for third parties

- Cryptoeconomic tools: <u>enablers</u> of new mechanisms; ‘sharing without sharing’
  - wide range of tools, incentivising participation (secure, fast, cheap)
  - support multi-party ‘token’ exchange: distributed (thus faster *and* more secure)
  - get rights if you meet certain conditions, computed over secret data
  - adversary types: honest but curious -> malicious -> colluding
  - simple -> complex protocols (comp. cost ↑)

SecureDataCloud (WP-E)
http://innaxis.org/securedatacloud/

Agents sometimes 'bend' the rules

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Thematic challenge 1 – Vulnerabilities and global security of the CNS/ATM system

Workshop: Date/location TBC – Bringing together the ATM community and security experts to enable a more privacy-preserving, cyber-resilient, fault-tolerant and secure ATM system.

Draft programme available shortly.

CNS/ATM … m present
vulnerabilit … these
vulnerabilit … , integrity
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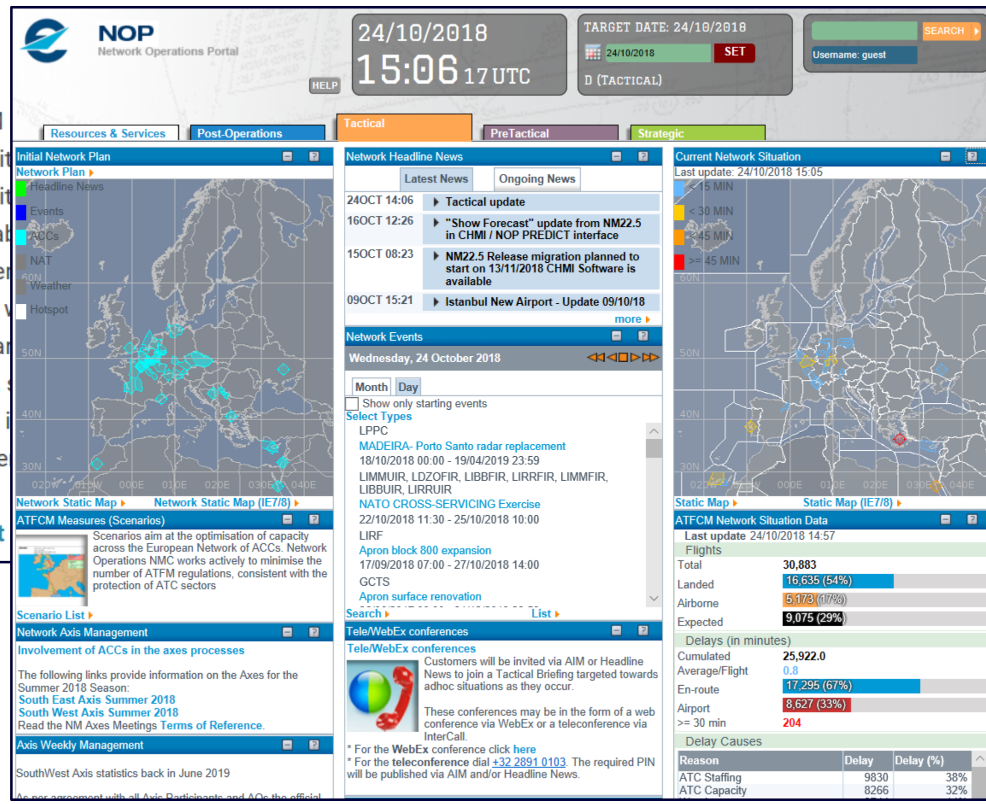
Fuller text



Cybersecurity not in scope for thematic challenge 4

DMAN A-CDM

Demand management – current and potential

Infrastructure of the aviation system

The aviation system is composed of two main infrastructural elements

- Airports
- Air traffic management (ATM)

There is not an unlimited availability of such resources

- The **runway complexes** of major airports are among the scarcest resources of today's international air transport system and will continue to be so in the foreseeable future
- In Europe **en-route airspace** also acts as a major 'bottleneck'

Since infrastructural interventions are difficult/expensive/environmental challenging, **demand management techniques** are put in place

Demand management

Administrative approach – in operations

- Airport slots (IATA guidelines and EC Regulations)
- ATFM slots (ground delay through First Planned First Served policy)

Slot

- Airport: the permission for a planned operation to use the full range of airport infrastructure necessary to arrive or depart on a specific date and time
- ATFM: a period of time within which take-off has to take place, namely between 5 minutes before and 10 minutes after the CTOT. The aircraft is required to be at the runway, ready for departure at its CTOT.

Market-based approach – in operations and **proposals**

- Airports
  - slots allocated through auctions
  - swapped through monetary trading
- ATM
  - Air navigation service charges – pricing mechanism
  - ATFM slot auction or trading

Demand management for airports

(Material on this slide for setting the comparative context)

Administrative approach

- IATA guidelines complemented by EC Regulations
- Primary allocation
  - Primary criteria
    - grandfathered (20%-80% rule), change-to-historic, new entrants, others
  - Secondary criteria
    - Year-round, type of route, type of service, type of market, and size of aircraft
- Secondary allocation
  - Slot swaps among airlines and IATA conference (twice a year)

Market-based approach

- Primary allocation
  - Auctions – vast scientific literature
  - Implementation in the US (2008) and China (2017)
  - Strong opposition from IATA, slot coordinators, and airports
  - Realistically, there is no hope to shift to this approach in the short-medium term
- Secondary allocation
  - Monetary slot trading among airlines (*limited implementation*)

Airport slots are not in scope for this challenge

Demand management for ATM

Administrative approach

- Tactical demand-capacity imbalances are managed through **ground delay**
    - Better to have an aircraft waiting on the ground than in the air
- In Europe, ATFM slots are allocated to flights according to the First-Planned, First-Served principle (CASA algorithm)
- Slot swapping is allowed but very little used
    - 1548 swaps over 9.6 million flights in 2013
- In case of multiple regulations, the most penalising regulation is used

Costs, charges and equity

FPFS minimises total delay, not total cost of delay

15 flights F1, F2, …., F15
15 slots: S1=[06:00 – 06:02], S2=[06:03 – 06:05], ……., S15=[06:46 – 06:49]

Flight	Delay Cost (€/min)	Planned entry time	FPFS		MinCost		FPFS vs Planned		MinCost vs Planned	
			Slot	Entry time	Slot	Entry time	Delay (min)	Cost (€)	Delay (min)	Cost (€)
F1	7	06:01	S1	06:01	S1	06:01	0	0	0	0
F2	10	06:03	S2	06:03	S2	06:03	0	0	0	0
F3	10	06:08	S3	06:08	S4	06:10	0	0	2	20
F4	7	06:08	S4	06:10	S13	06:40	2	14	32	224
F5	14	06:08	S5	06:13	S3	06:08	5	70	0	0
F6	16	06:15	S6	06:16	S5	06:15	1	16	0	0
F7	19	06:18	S7	06:20	S6	06:18	2	38	0	0
F8	14	06:19	S8	06:23	S7	06:20	4	56	1	14
F9	6	06:21	S9	06:26	S14	06:43	5	30	22	132
F10	19	06:22	S10	06:30	S8	06:23	8	152	1	19
F11	11	06:22	S11	06:33	S9	06:26	11	121	4	44
F12	20	06:28	S12	06:36	S10	06:30	8	160	2	40
F13	10	06:30	S13	06:40	S12	06:36	10	100	6	60
F14	12	06:33	S14	06:43	S11	06:33	10	120	0	0
F15	15	06:46	S15	06:46	S15	06:46	0	0	0	0
							66	877	70	553

Market-based approach for ATM demand management

Minimise the total cost of delay by swapping FPFS-allocated slots

- optimal swap by solving a linear programming problem

However, the true cost of delay for each flight has to be

- computed (easy task?)
- disclosed to the authority that performs the optimal cost allocation (?)

How to convince an airline to get a later slot for the benefit of the ‘society’?

- associate a value to each slot and buy/sell slots to offset delay decrease/increase
- how to define the slot value?

In addition, an airline may find convenient to misrepresent the delay cost (gaming)

- to minimise total cost, high unit costs are given small delay

However, minimum cost allocation can be obtained through a **distributed approach** implementing a **iterative, ascending type of auction**

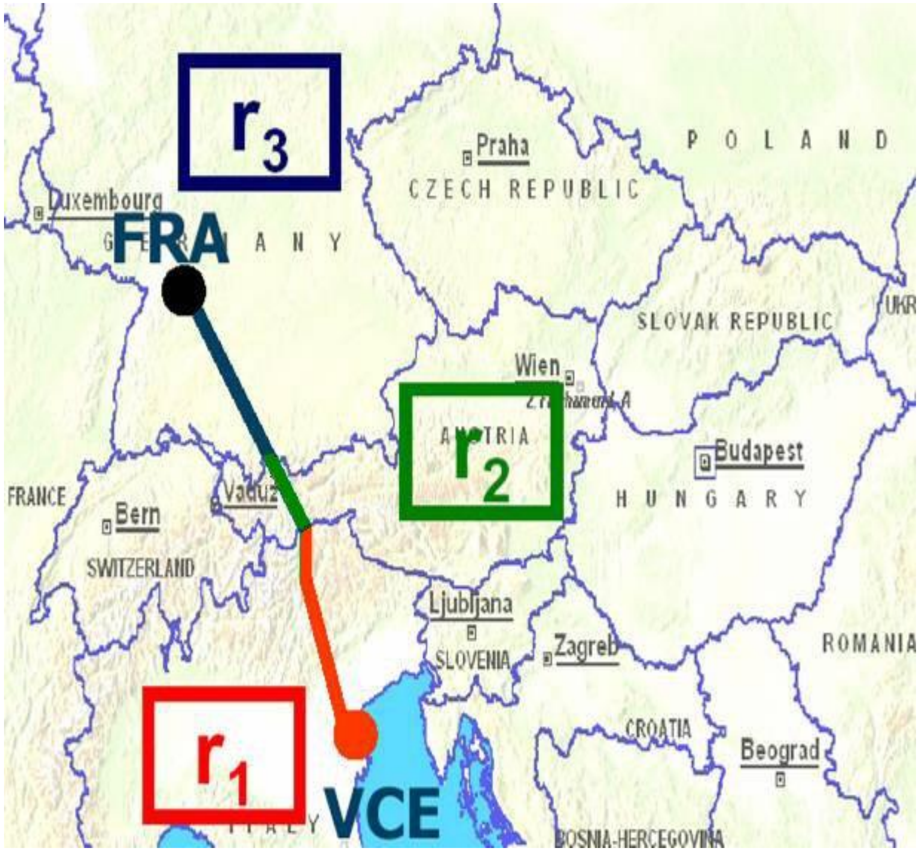
(Castelli et al., Transp. Res. C, 2011)

Equity (fairness)

Costs	Solution A	Solution B
Flight 1	1	5
Flight 2	2	5
Flight 3	12	5
Total	**15**	**15**

- Everyone is treated in the same way
  - No one is favoured by the mechanism
  - FPFS perceived as 'fair' by airspace users
- No one is penalised for not participating in a mechanism
- Equity: the actions of one airspace user must not impact another's flights
- When a social optimum is sought, e.g., min total cost, costs are evenly distributed across users
- Fairness comes at a price (Bertsimas et al., Operations Res, 2011)

Air navigation service charges

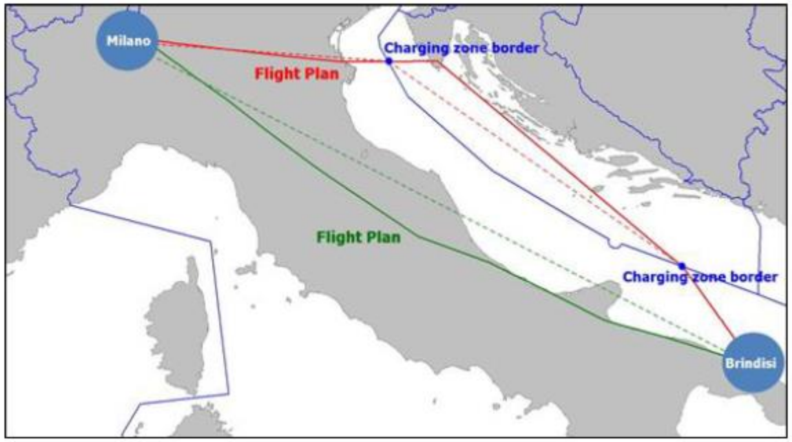


Total charge per flight	$R = \sum_{i=1}^{n} r_i$
National charge	$r_i = d_i * p * t_i$ Service Units
Distance factor	d_i
Weight factor	$p = \sqrt{\frac{MTOW}{50}}$
National Unit Rate	t_i

Pricing mechanism in European airspace

For an aircraft weighing 80 metric tonnes, the price per kilometre (July 2013) is €1.00 in Italy and €0.53 in Croatia.

The longer route (through Croatia) is therefore €177 cheaper.



Source: *PRB Annual monitoring Report 2012, Volume 1, European overview and PRB recommendations, Section 3.2*, 13/09/2013

Such a situation exposes the risk of possible unintended consequences of current rules:

- May constitute an incentive for airspace users to file longer routes with a detrimental effect on the horizontal flight efficiency indicator
- May create cost competition based on Unit Rates, in order to attract traffic

Modulation of ANS charges

Mitigate congestion

SES Charging Regulation 391/2013 – Art.16

Member States […] may […] reduce the overall costs of air navigation services and increase their efficiency, in particular by modulating charges **according to the level of congestion of the network in a specific area or on a specific route at specific times**. […]

The modulation of air navigation charges means a variation of the en route charge and/or the terminal charge calculated on the basis of the provisions of Articles 11 and 12.

- Users may fly longer routes to avoid ‘expensive’ countries and still get an economic benefit
- EC Regulation 393/2013 allows congestion pricing

- Several Exploratory Research studies
  - SATURN: peak-load pricing
  - COCTA: trajectory pricing
  - Vista, INTUIT, APACHE….
- **No actual implementation so far**

Initial challenges

Initial challenges

- We've hopefully set the scene for some presentations to follow
- Some initial challenges we'd like to flag: can/should we –
    - build better models to capture real slot management behaviour?
    - build better models to forecast real route planning behaviour?
    - carry out more research to inhibit gaming?
    - further explore distributed mechanisms for cost minimisation?
    - investigate issues of equity further, including stakeholder trade-offs?
    - build on research re. peak / trajectory pricing (COCTA to follow ...)?
    - integrate the two main themes of this workshop, i.e. embed agent 'irrationality' inside the development of new market mechanisms, or should we research them further independently, first?

Why do we need improved models in ATM?

Thank you

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