At the core of the Engage KTN is the definition of various thematic challenges: new ideas suggested by the research community, not already included within the scope of an existing SESAR project. They are developed along with the ATM concepts roadmap and complementarily with some of the network's PhDs and theses.

**Thematic challenge 4**

# Novel and more effective allocation markets in ATM

**Edition 2.0, November 2018**

*This is an evolving document that summarises the key concepts (and, later, findings) for thematic challenge 4.*

## Abstract

This research explores the design of new allocation markets in ATM, taking into account real stakeholder behaviours. It focuses on designs such as auctions and 'smart' contracts for slot and trajectory allocations. It seeks to better predict the actual behaviour of stakeholders, compared with behaviours predicted by normative models, taking into account that decisions are often made in the context of uncertainty. Which mechanisms are more robust against behavioural biases and likely to reach stable and efficient solutions, equitably building on existing SESAR practices? The research will address better modelling and measurement of these effects in ATM, taking account of 'irrational' agents such as airline 'cultures'. A key objective is to contribute to the development of improved tools to better manage the allocation of resources such as slots and trajectories, and incentivising behaviour that benefits the network - for example by investigating the potential of centralised markets and 'smart' contract enablers.

# Description of challenge

Air traffic management (ATM) is an example of a system where demand often exceeds capacity. In Europe, for a flight flying from a given origin to a destination, a shortfall in either en-route capacity (e.g. insufficient controllers to handle the flight) or at the destination (e.g. insufficient runway capacity to receive the flight), results in the flight being delayed at the origin until an appropriate trajectory and tactical departure slot are available. Each year, such delays generate large costs for the airspace users (airlines) and passengers. During such capacity constraints challenges remain regarding, *inter alia*, the trade-off between minimising the delay in the network as a whole and the delay for given airspace users.

This thematic challenge explores the design of new market mechanisms for the (re-)allocation of trajectories/routes and slots (often linked resources) to airlines in the tactical phase. "Market" mechanism does not necessarily imply the use of money as a medium for transactions. Moving beyond first-planned, first-served principles, matching market, centralised batch auctions, primary and secondary markets (double auction or bilateral exchanges) may each bring advantages. The challenge also seeks to explore better ways to predict the *actual* behaviour of stakeholders (airspace users in particular), compared with behaviours predicted by classical models, also taking into account that decisions are often made in the context of uncertainty. Such uncertainty may be aleatory (due to chance, such as weather) or epistemic (due to lack of information). The challenge poses questions such as: which types of mechanism are likely to work best in tactical slot and trajectory management[1], under different types of uncertainty and information sharing? Which mechanisms are more robust against behavioural biases ('irrationalities') and likely to reach stable and efficient solutions more quickly, e.g. without leaving unused slots? How can we equitably build on existing SESAR practices, such as Enhanced Slot Swapping, and planned SESAR functionalities such as the User-Driven Prioritisation Process (UDPP)?

A number of economic models applied in ATM (and air transport) are *normative*, such as Nash equilibria and linear programming. They make several assumptions about agent rationality that do not always work as expected predictors of behaviour. This is because real decisions are often made by human beings, or at least with human intervention, and are not fully 'rational', in the sense of adopting the solution suggested by some type of optimisation process. Behavioural science in general, and behavioural economics in particular, may bring complementary solutions to ATM in order to better predict actual behaviour in the network. Behavioural economics is based on a number of related principles, examples of which are summarised below:

- **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. "we will 'pay' as much to avoid an initial 15 minutes of slot delay, as to avoid a further (more expensive) 15 minutes of delay"
- **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

Whilst more broadly, behavioural science may consider aspects such as airline general 'beliefs' (or 'cultures', e.g. that a certain type of action results in a certain type of delay), behavioural economics tends to focus more specifically on understanding financial trade-offs, taking into account that agent rationality is 'bounded' (such agents are not willing or capable of solving complex optimisation problems, as they are assumed to in normative models predicting behaviour). Classically, market forces are often assumed to establish rationality and, ultimately, to produce a predictable equilibrium – although this is often not the case.

[1] Improved trajectory prediction *per se* falls within the remit of Engage thematic challenge 2.

Behavioural science, with behavioural economics, thus focuses on what agents *actually* do, rather than what they 'should' do, and is driven by *descriptive* models. This thematic challenge may thus investigate the extent to which ATM can move from objective functions to 'subjective' functions, i.e. that take account of 'irrational' agents. In a 2014 review, Whitehead *et al*. (2014) state that "the behavioural sciences are clearly having a global impact on public policy initiatives [...] 136 states have seen the new behavioural sciences have some effect on aspects of public policy delivery in some part of their territory [...] 51 states have developed centrally directed policy initiatives that have been influenced by the new behavioural sciences." Several ATM stakeholders have expressed a need to take advantage of behavioural science to improve operational predictability. However, notwithstanding limited examples considering actual human behaviour in the context of wider transport planning and environmental policy (e.g., Avineri, 2012; Garcia-Sierra *et al.,* 2015), there are no known formal considerations of the applications of behavioural science in ATM.

Several SESAR exploratory research (ER) projects (e.g., SATURN, ACCESS, COCTA) have advanced the market mechanism state of the art already, exploring ways in which the efficiency of existing solutions might be improved, including market-based demand-management mechanisms for air traffic flow management (Bolic *et al.*, 2017; Castelli *et al.*, 2011), auctioning for strategic airport slots (De Neufville and Odoni, 2013; Herranz *et al.*, 2015), and controlling tactical delay distributions to minimise propagated delay and increase adherence to (strategic) airport slots at coordinated airports (Ivanov *et al*., 2017). Further development opportunities lie ahead, in that modelling in these domains variously investigates the optimal use of limited capacities but (necessarily) assumes unbounded rationality, for example regarding flight scheduling and demand management that might "create opportunities for strategic behaviours from the airlines, i.e., potential incentives to provide scheduling inputs that do not reflect their true preferences in order to gain a strategic advantage over their competitors" (Jacquillat and Odoni, 2018). Regarding airport capacity and demand management, these authors further comment that "abstractions and simplifications of reality that necessarily underlie these mathematical and simulation models cannot fully capture all the operating complexities found in practice". In a comprehensive review comparing and contrasting the operations research and economics perspectives in ATM, it is concluded that "significant opportunities exist to [...] extend the scope of economic studies to integrate more realistic models of flight scheduling and airport operations [...] addressing them incrementally would enable the development of cross-disciplinary approaches to airport demand management and more effective congestion mitigation policies" (Gillen *et al*., 2016).

Whilst **(strategic) airport slots are not in scope for this challenge**, let us consider briefly a current tactical example. SESAR continues to develop UDPP to achieve additional flexibility for airspace users to adapt their operations in a more cost-efficient manner. This makes use of mature mechanisms such as Enhanced Slot Swapping (deployed in 2017) and continues to validate mechanisms such as fleet delay apportionment and selective flight protection (Pilon *et al*., 2016). It is also exploring future options for even greater flexibility regarding cost minimisation and equity for 'low volume' airspace users with less market power, although integration of accurate airline decision-making and cost models in this context remains a challenge, and the best models to date assume unbounded rationality and utility maximisation (Ruiz *et al*., 2017).

Behavioural science is not a panacea with regard to resolving certain shortcomings of the classical approaches to operations research, and assumptions of utility maximisation, for example, that still serve the ATM community well. Nor can it model the full scope of agent subjectivity. Rather, this thematic challenge seeks, *inter alia*, to identify and explore key areas in which behavioural science may advance the state of the art regarding ATM modelling, complementarily bridging existing gaps. This will involve identifying methods and solutions where an absence of behavioural modelling is particularly likely to compromise model usefulness and, where possible, to collect evidence of such (anticipated) shortfalls. More broadly, can we identify the first steps towards improved tools to better manage the costs of delay, and of uncertainty, and to better incentivise behaviour that benefits the network, in the wider context of tactical slot and trajectory allocation? What new technologies might be appropriate to support the negotiation of tactical contracts? For example, might cryptoeconomic tools[2] have a role to play in delivering 'smart' contracts? From a user-acceptability perspective, could such tools deploy a centralised market with real money, or would only 'credits' be acceptable?

[2] Note that vulnerabilities and global security of the CNS/ATM system falls within the remit of Engage thematic challenge 1.

# Workshop conclusions

Behavioural science could be used to better capture 'irrational' (non-normative) behaviour from airlines in future, and build improved models, for example in terms of (tactical) routing and slot choices. This could deliver improved forecasting and traffic demand tools for ANSPs, and better predict behaviour under UDPP (for example) by validating key prospect theory principles, such as loss framing, risk-seeking behaviour under loss, and endowment effects. New market designs for the allocation, and trading, of tactical slots may support potential future mechanisms for slot swapping and trading between different airlines. Key to such progress will be understanding ways to more effectively manage airspace user cooperation and motivation, how these vary by airline type, and whether incentives or penalties work better. Is the better underlying driver of behaviour cooperation or competition, and can social norms be used to make airline behaviour more collaborative? The objective is to offer airspace users improved choice, whilst avoiding undesirable behaviours, such as gaming of the system. Improved definitions of 'equity' and 'fairness' are needed, potentially differentiating or consolidating the two terms, examining the definitions and trade-offs across different stakeholders (e.g. airports treating all flights equally, unlike airlines), plus trade-offs with flexibility. Are there ways in which tactical uncertainty could be exploited to offer more flexibility to airspace users? There is no unique way to define equity and fairness, since these may or may not invoke monetary value, and may depend on the stakeholder perspective and impacts, both at the local and network levels. Further work is also needed on the precise definition of the 'best' trajectory[3], by stakeholder type, not only across airspace user types. Greater elucidation is required of the need to adopt a compromise between individual rationality, budget balance, allocative efficiency and incentive compatibility (see Castelli *et al.*, 2011) in the design of new mechanisms. This should build on existing exploratory research in SESAR examining the trade-offs between centralised and decentralised markets. As raised above, part of the move towards improved models of stakeholder behaviour could assess gaming, and mature the state of the art advanced by projects such as AeroGame[4], which investigated how serious games can support change in ATM. It is necessary to model more realistic human interactions in a multi-stakeholder, complex socio-technical environment, rather than in highly constrained and limited simulation environments, and to determine which (incentive) solutions are best in terms of non-manipulability (Schummer and Abizada, 2017; Schummer and Vohra, 2013).

The robustness of (tactical) slot allocation mechanisms and airspace users' choice of flight plan as a function of time is made more difficult to predict in the context of uncertainty from exogenous factors and the airspace user's response to the evolving traffic situation as they adapt from the originally-filed flight plan. Integrating new behavioural models with a more systematic exploration of the impact of computer-based flight planning and how this responds to different scenarios, with models of feedback loops and inclusion of machine learning could also be beneficial[3]. Airspace user cost functions need to be taken into account, and may be usefully framed in terms of flexibility characterisations, such as elasticity functions and 'not before' and 'not later than' departure rules. Such functions and rules could be deployed to empower airspace users to make better choices. Additional investigation of the potential role of ANSPs coordinating with the Network Manager to manage tactical demand (and route choices) is required, building on the work of COCTA, for example, assessing the impacts of uncertainty and disturbance, and the implications for policy recommendations regarding the Single European Sky performance scheme. Barriers to progressing the state of the art include the calibration and validation of new models such as those identified above, and obtaining quality stakeholder cooperation and buy-in. This might be overcome by running models and tools in shadow-mode, with usable and practical user interfaces, also demonstrating their value in terms of metrics such as predictions of (sector) overloads, delays and delay costs, and valuations of equity, fairness and efficiency. Data collection quality could be improved through the use of stated preference techniques, commonly deployed in socio-economic and psychological research, and sensitivity analyses would need to be run to test model and tool efficacies. Capturing gaming behaviours often requires projective techniques. Ultimately, can the two main themes of this challenge be integrated, i.e. embedding agent 'irrationality' inside the development of new market mechanisms?

[3] Improved trajectory prediction *per se* falls within the remit of Engage thematic challenge 2.

[4] https://www.sesarju.eu/newsroom/brochures-publications/aerogame

**The following have been identified as *example* ideas for potential further exploration:**

1. Incorporating behavioural science methods into improved traffic demand and distribution predictor tools for ANSPs and UDPP;
2. Assessing if incentives or penalties work as better drivers of behaviour: whether social norms can be used to improve collaboration;
3. Predicting and avoiding undesirable behaviour, such as gaming, in ATM allocation mechanisms;
4. Building a better understanding of 'equity' and 'fairness', plus trade-offs across different stakeholders, and with 'flexibility';
5. Improving the assessment of uncertainty and disturbance, and of new mechanism implications for policy recommendations;
6. Running models and tools in shadow-mode, with practical user interfaces and value in output metrics (e.g. costs, overloads).

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