Exploring future UDPP concepts through computational behavioural economics

Executive summary

The goal of the project is to develop new modelling approaches enabling a rigorous and comprehensive study of highly flexible, advanced UDPP mechanisms. To this end, it adopts the paradigm of computational behavioural economics, as a particularly suitable framework for the representation of features that are not properly captured by classical approaches, such as bounded rationality, hyperbolic discounting, and asymmetric, imperfect and uncertain information.

The project started by defining a set of Key Performance Areas (KPAs) and Key Performance Indicators (KPIs) for the comprehensive assessment of the impact of the different flight prioritisation and trajectory allocation mechanisms. While looking for maximum alignment with the SESAR Performance Framework, the project has also proposed some additional KPAs and KPIs to address aspects that have received less attention in previous studies, but are however considered essential for a thorough evaluation of flight prioritisation mechanisms, such as equity and robustness against unexpected AU behaviours. The proposed assessment framework, which was refined and validated through a dedicated stakeholder workshop, encompasses 5 KPAs: Predictability and Punctuality, Flexibility, Access and Equity, Cost Efficiency, and Robustness.

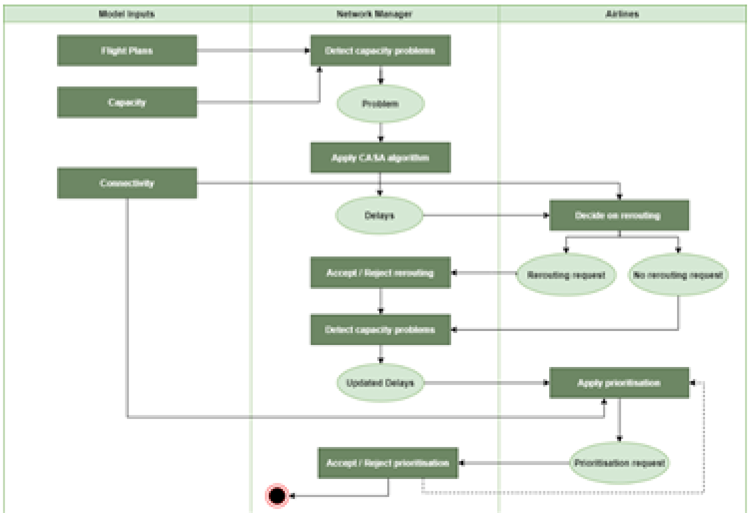
A detailed literature review served to identify the tactical slot and trajectory allocation mechanisms that have been proposed in previous research. From this initial list, a subset of mechanisms was selected for simulation within the project. The selection criteria aimed at exploring a range of mechanisms providing different levels of flexibility, from the instruments proposed so far by SESAR to more complex and flexible mechanisms. The final set of mechanisms that were modelled and evaluated includes: (i) a baseline mechanism representative of current operations, consisting of the First Planned First (FPFS) policy and the solutions provided by SESAR UDPP Step 1 (Enhanced Slot Swapping, ESS); (ii) Selective Flight Protection (SFP); (iii) Enhanced Selective Flight Protection (ESFP), also known as Flexible Credits for Low Volume Users in Constraint; and (iv) Slot Auctioning.

To evaluate the impact of the selected prioritisation mechanisms on the proposed KPIs, the project has developed an agent-based simulation model. The model, which simulates air traffic during a day of operations, comprises three main elements:

- A network formed by a limited number of airports and airspace sectors. The goal was to work with a simplified network, but complex enough to study the emergence of network effects.
- The agents: the Network Manager, in charge of flow management, and AUs, which make decisions on how to deal with ATFM delays. The rules governing these interactions depend on the prioritisation mechanism implemented in each simulation scenario. AU agents can be configured to behave as rational cost minimisers, but also to incorporate non-rational behaviours based on the insights provided by behavioural economics, such as loss aversion, endowment effects, bounded rationality and hyperbolic discounting.
- A set of exogenous variables, which represent external conditions that affect the model but are not affected by it, such as fuel prices, air navigation charges price, and airlines' cost index.

The simulation comprises four main stages: in the first stage, the Network Manager estimates the future demand for all the sectors within a given time window. If the Network Manager detects a demand-capacity imbalance, it initiates a regulation. In the second stage, delays are calculated and assigned to each of the flights affected by the hotspot. In the simulations based on the FPFS principle (baseline, SFP, ESFP), the Network Manager sequences the flights in the order in which they would have arrived at the constrained airport or sector according to the filed flight plans. In the simulations

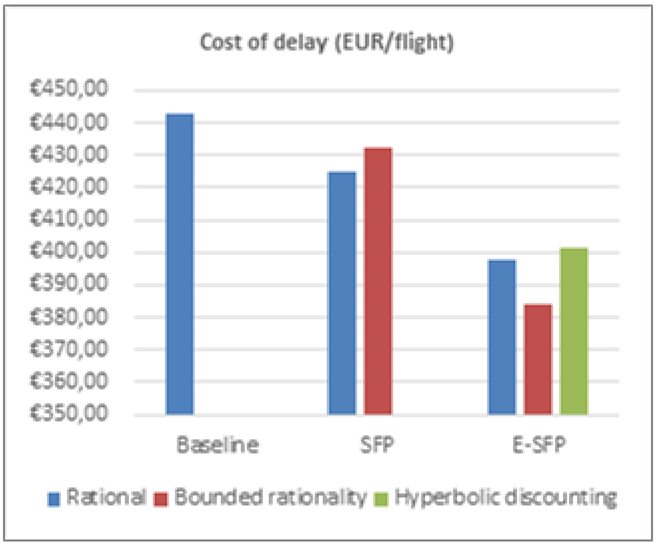
based on the auction paradigm, the sequence of flights is the result of the successive auctions of all the slots inside the hotspot.



Simulation workflow for mechanisms based on FPFS

The third stage comprises the decision process of the airlines: once the affected flights receive an initial ATFM slot, the AUs evaluate all possible actions with the objective of reducing the cost of delay, according to the rules imposed by the prioritisation mechanism that is being simulated. Finally, the Network Manager accepts or rejects the requests sent by the airlines. Once this process is completed, delays are definitive and the model computes the different KPIs.

In the last stage of the project, the selected prioritisation mechanisms were simulated under a variety of scenarios with different levels of congestion and various combinations of AU behaviours. The simulation results allowed the extraction of a number of interesting conclusions. The experiments show that network effects have a strong impact on the KPAs under study. As expected, they confirm that the ability to reduce the cost of delay is directly related to the flexibility provided by the mechanisms, with the auction mechanism providing the most cost-efficient results, but some unexpected and non-trivial phenomena are also observed: for example, the SFP mechanism only outperforms the baseline scenario when combined with the rerouting of some flights. The model has also allowed us to explore how different behavioural biases affect the resulting performance, and how the benefits of each mechanism are distributed among the airlines depending on the characteristics of their network, their business model, and their decision-making strategy.



Example of simulation outcomes

Future research should address questions such as the exploration of other network configurations, more complex airlines strategies and more extreme behaviours, and the extension of the simulation time frame in order to incorporate airlines learning capabilities and adaptive behaviour. A proper understanding of these questions will be essential to achieve a rigorous and comprehensive assessment of innovative prioritisation mechanisms.

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