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BEACON

BEHAVIOURAL ECONOMICS FOR ATM CONCEPTS

This Project Management Plan is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No [893100] under European Union’s Horizon 2020 research and innovation programme.

Abstract

This Technical Report presents an interim synthesis of the stakeholders' input and the specifications stemming from internal discussions and the stakeholder workshop. It presents the main issues related to the concepts attached to the mechanisms selected in D3.1, for instance in terms of market mechanism design. Following the output of these discussions, some specifications for the project, and sometimes for the models, are laid out.

Table of Contents

List of Tables

List of Figures

1 Introduction

1.1 Scope and objectives

The core goal of BEACON is to study potential extensions to the User Driven Prioritisation Process (UDPP) mechanisms (current and those still in research stages)[1], aiming to increase further the flexibility by allowing exchanges between airspace users (AU), taking into account at the design stage behavioural effects from users, and network effects triggered by aircraft turnaround processes, passenger connections, and airspace management.

The role of WP6 in general, and in this deliverable in particular is to make sure the concepts developed in BEACON are properly assessed from an operational point of view, not only from a purely academic one. In particular, we are interested in the point of view of airspace users, as they will be the main users of UDPP, but also of other actors who may be impacted by UDPP, like airports, Air Navigation Service Providers (ANSP) and the Network Manager (NM).

These points of view need then to be integrated as requirements for the rest of the project, sometimes in the form of monitoring an aspect (e.g. dynamics of re-prioritisation), sometimes in the form of pre-analysis to the model (e.g. study incentives), and sometimes in terms of mechanism aspects (e.g. should support multi-regulation in a transparent way). Some requirements may be common to all mechanisms, others are more specific to one of them.

In BEACON, we are looking at possible implementations of mechanisms both at a medium-term horizon and a long-term one. As a consequence, operational requirements should not come only from the present system as it is now, but also from consideration of how the system would develop in the future with various SESAR solutions being implemented. BEACON is an exploratory research project, which means that it is at the start of the SESAR innovation pipeline.

Some exploratory, long-term mechanisms studied in BEACON may require significant operational changes. The extent of these changes should be assessed taking into account what other long-term solutions are currently being planned. A good example is the fact that some extensions of UDPP require a more uniform prioritisation process across the airspace. This implies more coordination between actors, in short more collaborative network management processes, which is an area studied for instance in PJ.09-03. When the mechanisms are more mature, towards the end of the project, we will thus assess its interaction with other 4D trajectory solutions[2], and highlight the differences, synergies, and potential incompatibility.

As explained more in detail in D3.1, the project started with a wide literature review on what has been done in the past for UDPP, but also what has been tested and what is envisioned. This led us to reduce the number of candidates to those for a medium-term and long-term improvement of UDPP. After this

[1] UDPP mechanisms currently under validation in SESAR2020 Wave2 - PJ07-W2 sol39.

[2] Addressed in SESAR2020 PJ07-W2 sol38

high-level selection, the project organised a workshop with the Advisory Board to discuss the mechanisms, in particular their main expected advantages and drawbacks, as well as any barriers to implementation. This workshop is presented briefly in section 2, and the detailed outcomes may be found in Annex A.

Following the workshop, the project has had various working sessions to discuss the feedback we got from the workshop and the mechanisms themselves. The main topics of these discussions are summarised in section 3. Issues about automation, credit creation/destruction, dynamics of slot allocation, entry costs for different mechanisms, have been discussed thoroughly, in particular with ECTL and SWISS, both members of the consortium.

The output of these discussions fed the deliverable D3.1 informing the final mechanisms selection (those to be implemented). Further, it impacted, to a lesser degree, the choice of metrics and scenarios, both important parts of the next steps for BEACON. Some requirements have been drawn for the next steps, all summarised in section 4. We noted in particular that some mechanisms required some pre-analysis through the use of very simple toy-model/s in order to quickly test some issues, like credit creation, incentive to cheat, etc. The list of requirements will guide the modelling process, in particular in WP4.

Finally, we highlight the next steps in section 5, in terms of future concept assessment.

1.2 Structure of the document

The document is structured as follows:

- Section 1 introduces the document explaining its aim and scope, and describes the structure of the report.
- Section 2 provides the concept scope and an overview of the first Advisory Board meeting.
- Section 3 presents the discussion of mechanisms.
- Section 4 summarises the requirements for modelling in BEACON.
- Section 5 highlights the next steps.
- Annex A presents details of the AB meeting discussions.

2 Concept scope and first advisory board meeting

The first Advisory Board (AB) meeting took place on November 11th 2020, in a virtual setting. The meeting main objectives were:

1. Present and discuss the pre-selected mechanism with the AB members.
2. Introduce the Behavioural Economics concepts to AB and discuss the decision-making processes during disruptions to help the project identify sources and types of "irrationality" in those processes.

The following sections give a short overview of the pre-selected mechanisms (for full details see D3.1), and the introduction to Behavioural Economics, as presented to the AB. This is followed by the description of the meeting itself and the attendance. Details of the AB discussions can be found in Annex A.

2.1 Pre-selected mechanisms

Table 1 lists the four mechanisms, the main prioritisation principles included in them, and short descriptions. More detailed graphical description of the mechanisms is given in Annex A, and for the detailed discussion on the pre-selection, please refer to D3.1.

Table 1. Pre-selected flight prioritisation mechanisms.

Mechanism label	Prioritization principles included
	1. UDPP Automation: UDPP – Flight Margins (FM) 2. Secondary 'market': Flexible Credits for LVUCs Based on airline prioritisations (UDPP flight margins), the NM[3] builds the slot sequence, sending the assigned slots to airlines. The airline evaluates the slot and decides on the possibility of absorbing some delay to earn credits, or to use some credits to prioritise one or more flights. They send the FCL request to the NM that accepts or rejects the requests based on schedule restrictions, and matching the accepted offers to produce the final UDPP sequence.

[3] We will refer to central agency and NM interchangeably throughout the deliverable.

B	1. UDPP Automation: UDPP – Flight Margins (FM) 2. Secondary 'market': Centralised Slot Trading Based on airline prioritisations (UDPP flight margins), the NM builds the slot sequence, sending the UDPP sequence to inter-airline slot swap offer provider (entity within NM). The provider, based on the prioritisation given by airlines tries to find inter-airline swaps to further reduce the impact of the regulation. Airlines evaluate the received offers and decide to accept or to refuse each offer.
C	1. UDPP Automation: UDPP – Flight Margins (FM) 2. Secondary 'market': Decentralised Slot Trading (Secondary Auction) Based on airline prioritisations (UDPP flight margins), the NM builds the slot sequence, sending the assigned slots to airlines. Airline evaluates received UDPP slots and decides on asking for a swap (selling or buying) from another airline. After receiving the trade result the airline sends the request (including the trade result) to the NM that matches received requests according to the schedule restriction, to produce the final sequence.
D	1. Primary slot auction NM communicated a list of available ATFM slots. Airline evaluates the cost of delay of its flights affected by the regulation, and decides to place the bid to try to win the slot. The slot bid is sent to NM that chooses winners to produce the final schedule.

2.2 Introduction to Behavioural Economics

The traditional economic approach bases its predictions and models on assumptions such as fully rational agents, maximising their utility at all times, over given and known preferences. Agents possess unlimited cognitive ability, and are able to objectively weigh up costs and benefits of choices. These assumptions of the traditional economic approach enable the use of well-formulated mathematical models, with convenient (mathematical) properties.

On the other hand, an individual makes about 35 000 decisions a day, and is not equipped with the unlimited cognitive ability. This illustrates the reality that the above mentioned assumptions of human rationality, utility maximisation and preference are often violated in the real-world settings. Behavioural Economics (BE) studies these deviation from rationality to explain and mitigate their impact in a systemic way. The models in the BE are usually descriptive, aiming to capture the actual behaviour. It is often difficult to mathematically formulate these models.

The following characteristics are used in BE to explain "irrationality":

1. Cognitive capacity - the human mind is very complex, but our cognitive capacity is limited and we do not fully weigh up our choices at all times - we take mental shortcuts and are prone to biases and non-rational behaviour (rational in terms of traditional economic theory).

2. Cognitive bias - is a systemic pattern of deviation from norm or rationality in judgement and decision-making, which is different from error (random deviation, no systematic pattern).

3. Overconfidence - can be divided into overconfidence in one's ability and overconfidence in the accuracy of one's knowledge. It can lead to excessive risk-taking and/or to a false sense of certainty for predictions.

4. Outcome bias - tendency to evaluate more favourably decisions that led to positive outcomes than the same ones that led to negative outcomes.

Prospect theory and hyperbolic discounting attempt to address the mentioned characteristics. Prospect theory is based on the idea that individuals make decisions based on their experienced value, which is measured as losses and gains relative to a reference point. In other words: people care more about changes in value than value itself. This is in contrast to standard expected utility theory (in which utility is generally calculated based on terminal levels). Moreover, prospect theory is based around an s-shaped value function, which is concave in the gain domain (risk aversion) and convex in the loss domain (risk seeking) (Grinblatt & Han, 2005). Loss-aversion describes a cognitive bias which manifests in the tendency to place a higher value on an item already owned, relative to its objective value (Kahneman, et al., 1991).

Hyperbolic discounting describes a time-inconsistent model, and is a cornerstone of BE. Given two similar rewards, humans tend to prefer the earlier reward over the later reward and consequently, sooner, smaller amounts are often favoured over larger, later amounts, to varying individual degrees (Kirby & Herrnstein, 1995). These preferences and measured indifference levels between delayed rewards in individual decisions make up subjective discount rates (Kirby, 1997). Making trade-offs of this kind, while employing the self-control required to delay consumption, is mental work. Heuristics are used unconsciously by people making these decisions for the purpose of efficiency.

A small survey including examples of mentioned biases was sent to participants of the AB meeting prior the meeting. The goal was the illustration of the "irrationality" inherent to human behaviour. The results were addressed in the Introduction to BE session (see section 2.3 below).

2.3 Meeting agenda and activities

The meeting agenda is listed in Table 2. The meeting consisted of presenting the project and the main concepts to the members of Advisory Board, followed by the discussions. There were two discussion sessions, each having the participants divided in two groups to ease the discussion in the virtual setting.

Table 2. First Advisory Board meeting agenda.

Time	Session	Presenter/moderator
9.00-9.10	Introduction	Gérald Gurtner (UoW), Nadine Pilon (ECTL)
9.10-9.30	General introduction of BEACON	Gérald Gurtner (UoW)

9.30-9.45	What to know from UDPP?	Nadine Pilon (ECTL)
9.45-10.00	First mechanisms selection in BEACON	David Mocholí (NOM)
10.00-10.05	Break	
10.05-11.20	Interactive session 1: Advantages and Limitations of mechanisms	Two moderators per room
11.20-11.35	Break	
11.35-12.10	Introducing behavioural economics in ATM	Benno Guenther (Salient)
12.10-13.05	Interactive session 2: Chains of decisions	Two moderators per room

The first presentation introduced the project, its main goals and tasks. BEACON's general goal is to explore the role of Airspace Users' (AUs') complex behaviours, such as bounded rationality, in the design of new management procedures, more specifically UDPP-like processes. The next session "What to know from UDPP?" explained in more detail the UDPP - the state-of-the-art and the new functionalities being explored in the industrial research project on UDPP (SESAR2020 Wave2 - PJ07-W2).

The session "First mechanisms selection in BEACON" presented the list of pre-selected flight prioritisation mechanisms, and their description. Then the mechanisms were delineated, and their functioning explained to the AB.

The first discussion session ("Advantages and Limitations of mechanisms") followed, where the participants were divided in two groups. The session was performed within the Miro platform, which eased setting up and conducting the discussion, with the added value of having the written trace of the discussed matters (see the snapshot of the discussion 1 in Figure 1). The discussion groups were also connected through the audio channel - one through the GoToMeeting and another through Webex.

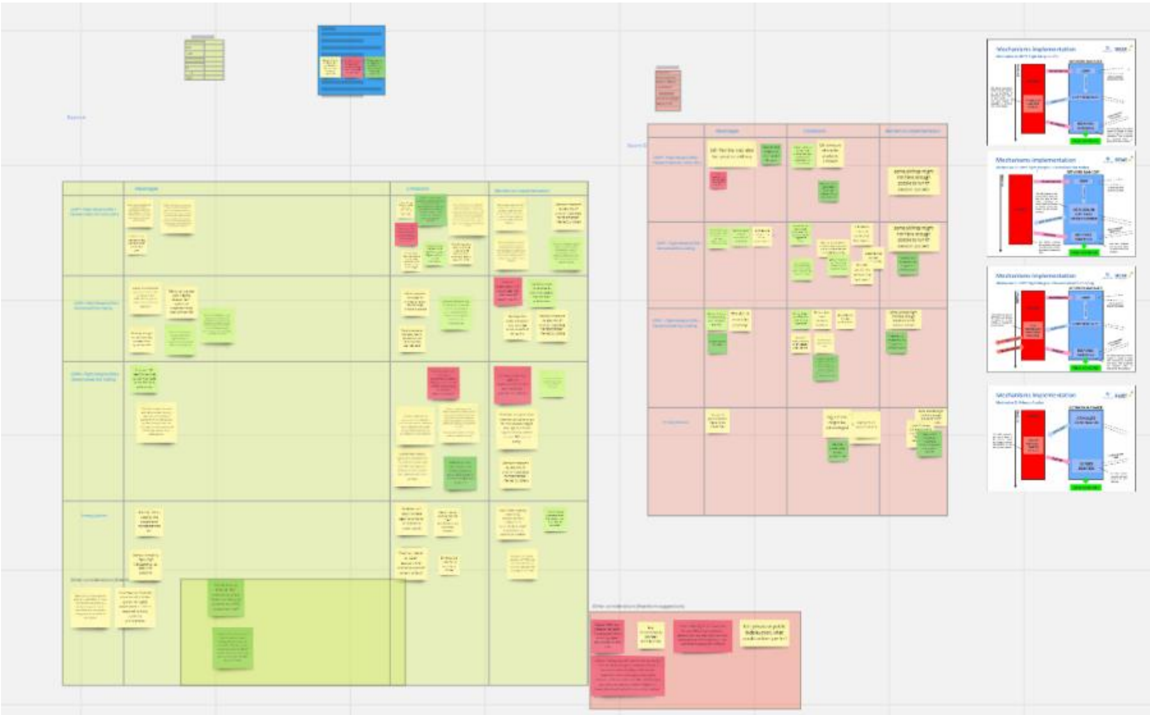

Figure 1. Snapshot of Miro board of discussion 1.

The AB gave their opinion on each of the proposed mechanisms, in terms of advantages, drawbacks, and barriers to implementation. The discussions are summarised in Annex A. Furthermore, this input was discussed in the consortium, in order to include all the relevant requirements in the final list of mechanisms to be implemented in BEACON. The discussion of concepts is described in section 3, the requirements in section 4, and the final list of mechanisms is described in deliverable D3.1.

Next, the "Introducing behavioural economics in ATM" session explained the basics of behavioural economics and its possible uses in ATM. Real examples of cognitive biases were presented, based on a small questionnaire sent to the participants a few days before. The discussion session on "Chains of decisions" followed, where the AB and project members listed and discussed important decisions during dispatching (and execution) through the specification of the information needed to make the decision (or the information that triggered the decision). The decisions were particularly focused on disruption management.

2.4 Attendance

The meeting was attended by eight AB members (see list in Table 3), and 17 project members.

Table 3. AB members in attendance.

AB member	Entity
Rita Markovits-Somogyi	HungaroControl

Adrian Clark	NATS
Dmitrijs Buiko	Air Baltic
Alon Lavi	El Al
Russel OLIVIER	Hop!
Derogee, Erik	Schiphol airport
Giuseppe Murgese	ECTL (as PJ07-W2 leader)
Eduard Gringinger	Frequentis (as SlotMachine coordinator)

The presence of several airlines (including SWISS from the consortium) was extremely valuable, as they are the main users of the mechanisms developed in BEACON. Having an airport representative was also very useful to understand a bit more what kind of processes need to be put in place at the airports in order to accommodate AUs' flexibility. Finally, the presence of ANSP representatives was crucial, in order to discuss network effects triggered by the mechanisms.

3 Concept discussion

3.1 Advantages and drawbacks of mechanisms

The workshop and other internal discussion, notably with SWISS, have highlighted a few important facts about the mechanisms under review (see Table 1 in section 2.1).

First, from the point of view of airlines, the line between oversharing information and keeping sensitive information is very thin. For instance, they have no problem with sharing margins, which represent the main (or first) steps in their costs function, but not the cost itself. While this may change if the privacy of their data was ensured, there is still the overarching issue of how to convince airlines to report their true costs. Indeed, inflating costs may lead to better situation for them in case inter-airline slot swapping is allowed, which may lead to system underperforming as a whole.

Adding credits or some other kind of bargaining mechanism is thus necessary to ensure demand (lower cost for AUs) is met by supply (slots).

3.1.1 UDPP + flexible credits.

Injecting credits on top of existing UDPP mechanisms to allow flexibility over time – with credits from one hotspot being used in future hotspots – seems an adequate solution, as described in D3.1 and based on (Ruiz, et al., 2019). The workshop participants thought that it would bring a nice flexibility to the system. However, there is still a fear that it does not rule out domination by some airlines. In fact, this is highly dependent on some rules, like how credits are allocated and created in the first place. This “monetary volume” problem is a common one in economics, and a complex one (see 3.2.3 for a short discussion). Moreover, credits may need to have different values at different hotspots, which raises the question of the exchange rate, another complicated topic.

From the implementation point of view, the main barrier might be the difficulty to reach consensus on how credits are earned, spent, and exchanged.

3.1.2 Flight Margins (FM) + Centralised Slot trading

A centralised slot trading is an alternative to paying credits. In this case, the central broker/agency (possibly NM) uses already available information given by the airlines (margins, priorities) to infer their costs and suggests slot swaps. Because the information used is in fact relative to each airline, the central algorithm has to make some renormalisation assumptions in order to compare priorities across airlines.

This mechanism has the advantage to potentially reduce the workload of the airlines by offloading the computation of the potential swaps to a central agency. The airports may also have a greater predictability, since swaps computed by the central agency would be performed from the system (cost optimal) point of view, and thus the final state of the slots allocation could be reached quickly. Moreover, it would be easier for airlines to have a single interaction point, instead of trying to interface with many airlines, as in the decentralised version (see 3.1.3).

However, it is worth noting that reviewing the swap offers may be cumbersome for airlines, especially when they do not have access to or do not fully comprehend the rationale behind the offers. It may be then that they try to change their priorities and margins in order to get something which is perceived to be (or actually is) better for them.

This is linked to the second major drawback of this mechanism: the central agency needs to be able to guess actual costs from the information given by the airlines. This is a tough task for three reasons:

- First, because margins and priorities maybe not be enough to approximate real cost function, for instance because of the presence of numerous jumps in the cost functions (e.g. due to different groups of connecting passengers).
- Second, because it is not clear how one should re-normalise margins and priorities in order for them to be comparable across airlines, and thus find inter-airline swaps. In particular, this raises important questions about equity and fairness (see section 3.2.4) among airlines.
- Third, because airlines may try to “cheat” and modify their priorities/margins in order to gain some advantage.

The main barrier to the implementation of such a mechanism may very well be, once again, the difficulty to reach an agreement on the above. However, other concerns were also highlighted during the workshop. In particular, the problem of who would bear the cost to run such centralised system is still open. Security over data sharing has also been cited as a concern, since the mission of the central agency is to rebuild airlines' cost functions, which are very sensitive. Note that other initiatives plan to use some technology to allow the central planner to use costs from airlines without the latter having to disclose them explicitly, in particular through a blockchain in the ER-4 project SlotMachine[4].

3.1.3 Flight Margins (FM) + Decentralised Slot trading

An obvious possibility to avoid asking the airlines to disclose their costs is to let them suggest swaps themselves. In this case, flight margins and priorities would only be used in a first step intra-airline, and then airlines would be able to make swaps among themselves.

The obvious advantage of this mechanism is its flexibility and easiness to implement. There would be no confidentiality issues in implementing it as the airlines would not be required to share their cost function, and the cost of running it would be mostly decentralised.

However, this solution has many drawbacks. The main one is the major workload induced by the computation and offering of slot swaps for airlines. The asymmetric effort of having to offer a slot swap – as opposed to just waiting for an offer – may be too high and hinder the actual benefits of this mechanisms. Asymmetry of information may be another major issue, as airlines may be reluctant to accept swaps based on the belief that other airlines may have other (better) information. Finally, the bargaining phase may take much longer than in the other mechanisms, since airlines have to compute, compare, propose, and accept slots swaps. Furthermore, this mechanism might create issues of information sharing with other stakeholders (airports, ANSPs and NM) as they need to be aware of decisions taken to provide needed services. While this is true for all mechanisms, the decentralised nature of this one implies that airlines would need to deal with these issues more autonomously. See

[4] https://www.sesarju.eu/node/3687

also sections 3.2.1 and 3.2.2 for a discussion on other stakeholders' constraint management and information sharing.

The manpower required by each airline would thus be significant, and many airlines could not or would not want to use this mechanism on this basis, which would be a major barrier to the (fully efficient) implementation of this mechanism.

3.1.4 Primary auction

In the spirit of letting the airlines decide what is good for them instead of trying to guess their cost function, one can also let them decide a priori what they would like as slots, and how much they are willing to 'pay' to get them. In this case, a primary auction where airlines bid for slots when a regulation is issued may appear to be a good option, theoretically.

An advantage of this type of mechanism is the simplicity and transparency. The auction is also an efficient resource allocation mechanism, since airlines bid only up to how much the slot is worth for them. However, once again, there may be a high effort needed from the airlines to estimate what they should bid in order to have the best deal. Bigger airlines may be advantaged in this sense.

Moreover, the auction would be using credits instead of real money, see 3.2.3. Consequently, this mechanism would need to carefully choose how credits are created and spent, even thought it may be slightly easier than in the previously described mechanisms, since exchange rates would not need to be computed (they are fixed by the market).

The auction solution may also be less resilient over time than the other solutions. Indeed, an auction would happen every time a regulation is issued. The slots would thus be definitely set after this auction (except when there are other regulations affecting the same flights, see below). If the situation of one flight changes, which according to the airlines happens quite frequently, they would not be able to change their slot any more, which is not the case for the other solutions.

The case of multi-regulated flights is also a problem. For instance, let us assume that a flight is involved in an en-route regulation, so the airline participates in the auction and "buys" an ATFM slot (spending some credits). Later, the NM detects another imbalance at airport X, affecting the same flight than before. The question is then whether the fact that the airline has already participated in an auction before, and therefore has spent some credits on freezing its flight in time, exempts it from participating in this second auction. If the answer is yes, the slot corresponding to the time in which that particular flight arrives at airport X would be fixed and would not be part of the second auction. If the answer is no, the airline would have to participate again in the second auction, which, implicitly, is associated with the loss of having "bought" the right to enter the first congested sector in the previously chosen slot, because probably this time will change depending on the second auction result.

If the above drawbacks can be mitigated, we also expect two main barriers for implementation. First, the overall cost of running auction for every single regulation may be higher than the benefits gained from the extra flexibility. Second, airlines are reluctant to consider primary auction, as they consider (rightly so in the current operational environment) that they already paid for the ANS service through the route charges, and this is a part of the service. This type of solution would thus require a much deeper change of paradigm before airlines would be ready to accept it.

3.2 Other issues discussed with airlines and other stakeholders

3.2.1 Airline flexibility vs airport uncertainty

While the mechanisms presented above are interesting to solve the problem of slot allocation, they cannot (for now) help solving the problem of the resource allocation at the airports. Indeed, each change of plan (slot allocation/swapping) may require a re-allocation of resources for airports. This re-allocation is a complicated task in general, since it involves different processes (catering, fuel, gate allocation, etc.) that need to be synchronised.

To reduce the complexity, the airports would prefer to have one party with which to maintain active communication (like in the centralised mechanism), which they feel would enable greater predictability of the changes that will occur in the schedule.

More generally, any flexibility (in time) given to the airspace users will translate into some uncertainty for the airports. Uncertainty has direct consequences on capacity, and sometimes on cost or even safety. It is however interesting to note that airport representatives overall think that a higher degree of uncertainty may be accommodated by airports, provided that a cut-off time for the change of slots exists. This has already been discussed and agreed in SESAR2020 PJ07 UDPP, and a cut-off time seems to be consensual among airlines and airports.

3.2.2 Airline flexibility vs network uncertainty

For exactly the same reasons, any flexibility given to the airline may impair capacity, cost, and/or safety from the airspace management point of view. In particular, it is clear that some slot allocations may trigger chain reactions in which additional regulations are needed. For example, if regulated flights due to the assigned delays saturate another point in the network that would then require a new regulation. This implies that UDPP cannot be a local process, but needs to take into account the entire network.

This is not a new topic, but past projects on UDPP were focused on local solutions, due to the technical complexity of the simulations and also to the late definition of coordinated processes between ATM actors (NM, ANSP, APT) to decide on accepting flights swaps. The UDPP concept's network-wide scope has been recognised since long, and the network complexity is now progressively introduced in the validation in SESAR2020. For instance, preliminary results from the Engage catalyst project led by Nommon, suggest that network effects are important (González, 2019).

Note that this uncertainty is inherent to regulation themselves, due to time fluctuations in the demand, and not only to UDPP, which only adds to it. Indeed, airlines for instance can use flight level capping to avoid regulations, which implies that other adjacent sectors may suffer from unforeseen overload.

In other economic systems (like financial ones), uncertainty typically has a cost, and thus can be priced. When capacity restrictions are in place, this is even clearer: uncertainty leads to over-provision of capacity, which in a stochastic system is always wasted at some point. The cost of the over-provision is thus the direct cost of uncertainty.

The current airspace system takes this into account only indirectly and in an aggregated way. Indeed, if higher uncertainty takes place in an airspace, ANSPs have to increase their capacity, which turns into higher unit charges. This way, the cost of uncertainty is borne by all AUs at the same time, and not specifically by airlines creating the uncertainty.

The management of uncertainty is typically a topic for 4D trajectory management. For instance, the COCTA project suggested to use contract between airlines and ANSPs/NM, with contract having more flexibility sold at a higher price. BEACON touches this subject because in the airspace, time and space are tightly related through the possibility to shift trajectories and delay flights. Thus, to have a true and fair resource allocation, UDPP needs to eventually shift from a local time allocation problem to a network-level time and space allocation problem.

3.2.3 Money vs credits

In all our discussion with airlines, one thing is clear: they do not want to use money at any point during the UDPP process. There seems to be two main reasons for this. First, they have already paid for air navigation service, and they do not want to pay twice for it. Second, the airlines' centres of operation do not deal (explicitly) with money in the current situation. Instead, it is their objective to mitigate the operational impact of disruptive situations, which later affects the cost of the operation. Changing that would require quite a lot of effort from the airlines.

One way to get around this is to create a dedicated "currency" for trading, typically called "credits". Mechanisms using credits need to have rules at least on:

- how the credits are created, e.g. fixed sum per airline per year, or per flight, per passenger, or gained through some mechanism (delaying flights) etc.
- how the credits are destroyed, e.g. when an airline buys a slot, the credit goes to the NM, which destroys it.
- where and when credits are valid, e.g. in which other regulations/type of regulations you can reuse credits previously earned.
- whether they can be exchanged (sold and/or bought) against 'real' money.

Note that credits may have a more or less direct relationship with real money. Indeed, in an auction mechanism for instance, each airline will compute how much a slot is worth for them, and will spend a certain number of credits. This creates automatically an exchange rate between money and credits, which is valid for a given airline. This exchange rate may be dynamic in time, depending on the monetary mass (essentially the inflation in credits). Moreover, depending on how credits are created in the first place, this exchange rate may be very similar across airlines, essentially creating an exact substitute for money. If from a theoretical point of view, money and credits are thus equivalent in some cases, from an operational point of view it is much easier to handle credits, even if these credits can be cashed at the end of a certain period for instance.

3.2.4 Equity and fairness

Any changes in the current allocation may trigger some differential advantage between airlines. For instance, maybe with auctions big airlines get a large advantage because of the number of slots they can trade, and small airlines do not. In this case, airspace users may not be happy with the implementation of a mechanism which will give an advantage to their competitors.

This is the vast subject of what is equitable or fair and what is not for airspace users. Deliverable D3.1 presents some consideration on this subject, in particular defining some indicators in this area. The definitions of equity and fairness that will be used in in BEACON are the following, derived from the SESAR UDPP programme:

- Equity is the idea according to which the actions of one AU must not negatively affect another's flights.
- Fairness can be defined as the quality of distributing something among a set of individuals in a manner such that each receives a share that fulfils its individual satisfaction threshold.

In the equity and fairness area, one can make different choices:

- requiring that no airline loses from any allocation. This is very rigid and does not allow airlines to protect other flights in hotspot.
- requiring that no airline lose from allocations on the long run. In this case, gains (or avoidance of losses) are computed over lots of potential situations.
- require that some other equity metrics have a certain value on the long run. For instance, the deviation of delay across airlines need to be smaller than a certain value.

In BEACON, we have an entire task dedicated to this subject, the results of which are presented in D3.1.

3.3 Chain of decisions and behavioural economics

An important aspect of BEACON is the inclusion of behavioural economics into the models to see their effect on the mechanisms under test.

A part of the workshop was dedicated to this subject. As explained in the previous section, first part was dedicated to explaining the behaviour economics matters to the advisory board and clarify several notions, in particular the so-called ‘non-rationality’ of agents. The second part was dedicated to probing the decision-making processes of disruption resolution strategies.

The discussion was particularly interesting for us, full of specific details that will be useful in the project development, such as:

- the diversity of dispatchers' roles among airlines,
- the main variables taken into account by some dispatchers,
- the possible decisions offered to the airline/dispatcher in different situations,
- kind of decisions required by the airport in order to accommodate changes of plan.

3.3.1 The automation issue

Another important topic was raised during the workshop and afterwards by members of the consortium: automation. Indeed, it was clear that airlines need some automated procedures to make decisions in most mechanisms (including today’s), either externally provided (e.g. by the NM) and/or in-house. The degree of automation is an important topic. First, obviously, because it conditions the acceptability of the mechanism as their application at the network level would require numerous interventions (i.e. it is possible to have tens if not hundreds of regulations a day, depending on weather and other factors). Then, there are two intertwined issues linked with the automation - what (which part of the process) to automate and which actor introduces the automation (e.g. airlines, central agency, auction entities).

Further issue is linked to the attainment of benefits through the use of automation. Is automation performed at individual (decentralised) or centralised level? For instance, the NM may provide an algorithm to convert airlines' costs into bids for a primary auction. In another example, airline may want to design their own algorithm (or rely on human expertise) for instance. What goals the automation will have, will depend on the stakeholder developing it, and its purpose.

In any case, the central question of automation with respect to this topic is the following: if everything is automatised, is there room for behavioural effects? First, it is clear that these mechanisms will leave, at least in the first stage, the possibility for a human to override the automation. This, by itself, implies that behavioural effects can arise.

More importantly, algorithms are designed by humans, and take as input some pre-defined input, also chosen by humans. Both may be impacted by human biases. For instance, how to compute the loss due to poor On-Time Performance if the algorithm decides to delay the flight? Some airlines may have rules of thumb (embedding biases), others may use some multi-objective optimisation (embedding their own choice for optimality), while others may have computed a value for a minute of delay. Even in the latter case, will the airlines be ready to accept high risk situations, even if they may have a high reward? Without perfect information on the other airlines and the overall system, will they be able to properly estimate odds of further delays down the road for instance, when other airlines, other stakeholders, or random events create further disruptions? Will they even compute them? If not, they will probably embed some risk management tool inside the algorithm (or ask the central body to do it), which may lead to suboptimal decisions.

In other words, as always with automation, the human is not absent: his/her role just moves at the higher level of abstraction. This does not mean behavioural effects are unchanged. In fact, many algorithms are designed to reduce non-rationality in human decision-making processes.

3.3.2 Market mechanism, game theory, and behavioural economics

Another interesting topic when designing mechanisms is to make sure that they are not rendered inefficient by 'gaming' (and sometimes cheating) behaviours. This is not the domain of behavioural economics per se, because even with fully rational agents, this may happen. As an example, we have to make sure that there is an incentive for airlines to submit honest margins and priorities, if these are used to compare flights from different airlines in a global prioritisation mechanism, as envisioned by the "flight margins + centralised slot trading" mechanism (see 3.1.2). It is possible, for instance, that airlines misrepresent their margins and gain an advantage on other airlines.

Behavioural effects come on top of this phenomenon, complicating it. For instance, if the mechanism is known to have a fault in which one can cheat, then agents may be drawn to cheating, even if their net gain is negative by doing so. More importantly, in a stochastic 'game', as we have now with the slot allocation, the over or under estimation of odds may lead to strange decisions. Discounting future rewards, as in hyperbolic discounting, may have some similar effects.

4 Requirements carried forward

The workshop output and the consortium discussions, highlighted in the previous sections of this deliverable, helped specify how the project will reach its objectives.

First, the extensive literature review (presented in D3.1) helped us have a wide overview of the possibilities and plans for the next stage of UDPP. We managed to reduce the number of mechanisms to a few important categories, that we presented in the workshop. At this stage, the description of the mechanisms was still at a quite high-level, but the answers gathered during the workshop helped us to highlight the major potential drawbacks and benefits for each of them. This will help us design the details of the mechanisms to maximise the likelihood of getting the benefits of these processes and minimise the risk of having adverse consequences. In this section, we highlight the main requirements stemming from the discussions, embodied in the chosen mechanisms presented in D3.1.

4.1 Requirements across mechanisms

4.1.1 The overarching issue of money representation

First, it is clear that airlines do not want to use real money in their day-to-day operations. As a consequence, we will only use terms like “credits” to designate what airlines have to spend in order to ‘buy’ slots, priorities etc. Furthermore, airlines see UDPP and other mechanisms as a means of avoiding losses, not making gains. From a modelling point of view, it does not change anything, except, crucially, when it comes to behavioural effects (see 4.3). In any case, we will make sure to communicate the benefits of mechanisms as loss avoidance whenever possible.

When talking about credits instead of money, the question of credit creation/destruction is crucial, as highlighted in the previous section. So, one of the requirements for the project is to dedicate some effort to this question, both analytically and with various tests using numerical toy models. But in any case, we exclude the possibility for airlines to buy credits with actual money in any mechanism.

4.1.2 The role of airport uncertainty

For reasons highlighted in the previous section, airports are directly concerned by any increased flexibility awarded to the airspace users, which is the reason why BEACON has decided to include airports and ANSPs in the advisory board.

After considering their feedback, we think that BEACON needs:

- To keep an eye on the degree of volatility potentially created by the various mechanisms, by monitoring some appropriate metrics.
- Implement a cut-off time in the models, after which airline agents cannot change their priorities/slots anymore.

4.1.3 The role of airspace uncertainty and the integration with 4D trajectory concepts

Internal discussions and workshop output have convinced us that uncertainty for the airspace, in the form of network congestion cascade or other issues, has to be taken into account when designing a UDPP mechanism. As a consequence, we drew two other requirements for the projects:

1. A systematic assessment of the impact of the mechanisms on the network, in particular highlighting interactions between regulations.
2. A priori considerations, for each mechanism designed, about the rules to put in place to have a more uniform prioritisation process in the airspace, i.e. across hotspots. When possible, we will also highlight the possibility to integrate the mechanisms with other concepts, like 4D trajectories. In particular, if time permits, we may explore the possibility to extend the use of credits for instance to the space domain (3D trajectory).

4.1.4 Equity and fairness

Internal discussions on equity and fairness highlight the importance of testing several rules and see their impact on the system. As a consequence, we drew the following requirements for the project:

1. Define equity and fairness metrics (see D3.1) and monitor them in every mechanism.
2. Compute and compare how much airlines are gaining (avoiding the loss) in the long run for every mechanism. Highlight any mechanism that exhibits negative gains for any airline in the long run.

4.2 Requirements for each mechanism

4.2.1 UDPP + flexible credits.

This first mechanism has the advantage to be partly specified already, as it relies heavily on concepts already defined by UDPP in the past. Apart from the problem of credit creation/destruction highlighted above, there are several unanswered questions about how credits can be used, in particular the values of exchange rates in different hotspots. However, using already defined concepts (priorities, margins) is still an attractive option, since airlines are already familiar with them and the system can use them pretty easily. As a consequence, the project decided to pursue two avenues:

1. First, explore how “delays” can be bought and sold using credits. This possibility has to be tested further through very simple examples and toy-models.
2. Second, use credits to ‘buy’ more flexible objects, like priorities, and possibly margins. This line of enquiry is more in line with the 4D trajectory concept from SJU, as highlighted in 4.1.3. It will also be tested via small examples and toy-models before being assessed more in detail with WP4 and WP5 models if needed.

4.2.2 Flight Margins (FM) + Centralised Slot trading

In a way, this mechanism has the best specifications already, thanks to the prior work of some members of the consortium (UNITS in particular). Using the information used as input to UDPP to infer potential inter-airline slots allocations is an attractive solution, as there is no need to request new information from the airline. As highlighted, it is not clear if there is enough data in the system to infer cost functions and thus good slot allocations, so the main requirement for this mechanism is its efficiency, i.e. the fact it can suggest beneficial slots swaps to the airlines (at least on average).

4.2.3 Flight Margins (FM) + Decentralised Slot trading

This mechanism is highly problematic, as it relies on airlines interfacing with each other. Due to the potential high effort required from airlines to get slots, and the potential reluctance (i.e. asymmetry of information) described in the previous section, we believe that this mechanism may not be a good candidate for the future. As a consequence, we decided to drop it from the analysis and we will not implement it in the models.

4.2.4 Primary auction

Since auctions are known to be quite efficient as a resource allocation mechanism, we are confident that this mechanism will yield some interesting results. However, we are aware of a few important drawbacks, in particular the fact that running an auction for each regulation may be cumbersome, and that this mechanism is more rigid than the others, as it is very hard to accommodate changes of priorities from airlines or network instabilities, for instance ending up in multi-regulated flights. As a consequence, we drew the following requirements for this mechanism:

1. The necessity to find an acceptable rule for flights which happen to be affected by different regulations at the same time.
2. The exploration of the priority dynamics from the airlines, both due to changes of priorities from the airlines and other network disruptions. For this, we will contact the advisory board and pose more specific questions in order to estimate how often it they would need to change their priorities in real situations.

4.3 Requirements on behavioural study

An important part of the future work in BEACON will be to embed behavioural economic theory into our models. To do this, the output of the workshop is very valuable. In particular, it will help designing the questionnaire prepared in WP4, by using some of the situations, decision keys, and variables highlighted during the workshop.

4.3.1 Automation

The topic of automation is important, and the discussion summarised in the previous section will guide us to deal with it. We draw the following requirements:

1. We will systematically highlight the decisions that have to be automated, the ones that can be automated, and those that cannot, in each mechanism.
2. We will highlight the possible deviations from rationality that airlines may exhibit, even when automated tools are used, due to the implementation of different automated strategies, in particular regarding the objectives chosen and the input used by the algorithm.

It may be that in some mechanisms, behavioural effects may not play a major role, in which case we will make sure to highlight why and report this result. This is one of the core objectives of BEACON.

4.3.2 Market mechanisms

We cannot address in detail the topics of game theory and behavioural economics in market mechanisms in BEACON. Just studying the aspects the rational choices have on the mechanisms requires a massive effort. However, it is an important topic that we do not want to forget completely. For this, we drew the following two requirements:

1. First, we will use very small scale toy-models to study different flavours of the mechanisms on simple examples. This will help us estimate how strong the incentives are to cheat or game the system for instance. This will be done through analytical work, simple learning agents, or more advanced agents trained via reinforcement learning.
2. Second, depending on the results of the previous step, we will plan to use different models of agents in the models. Some may use rules of thumb, others may be more advanced. The models in WP4 and WP5 will have to be designed to support these different types of agents.

5 Next steps

The previous section highlighted how we are going to use the feedback in the future steps of the project. More specifically, we are entering a phase of tests and pre-analysis, and survey collection. The main two steps for the project are thus the following ones:

- First, WP4 is now starting, and we have had some preliminary in-depth discussions about the mechanisms. We are preparing the code to write toy-models and find simple examples, to test different flavours of mechanisms, trying to tackle some of the issues highlighted in previous sections. This pre-analysis will be reported in deliverables in WP4.
- In parallel, a survey is being prepared, and considerations about automation are taken into account when designing it.

The next deliverable from WP6 will be at the end of project, when results on mechanisms will be available and we will be able to assess each mechanism in depth: estimated quantitative efficiency, operational drawbacks, need for new processes, relationships with other solutions, etc.

6 Acronyms

Acronym	Definition
4D	four dimensional
AB	Advisory Board
ANSP	air navigation service provider
APOC	airport operations centre
ATFM	air traffic flow management
AU	airspace user
BE	behavioural economics
ECTL	EUROCONTROL
FCL	flexible credits for LVUCs
FL	flight level
FM	flight margins
LVUC	Low-Volume User Constraints
NM	network manager
OPS	operations
UDPP	user driven prioritisation process
pax	passenger

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Annex A

A1. Discussion 1 Mechanisms

The workshop participants were divided in two discussion groups. Each group used a portion of a Miro board for discussion of the proposed mechanisms, explained during the "First mechanisms selection in BEACON" session. The graphical depiction of the mechanisms (Figure 2, Figure 3, Figure 4, and Figure 5) and the summary of the discussions of both groups can be found in the following text.

UDPP – Flight Margins (FM) + Flexible Credits for LVUCs (FCL)

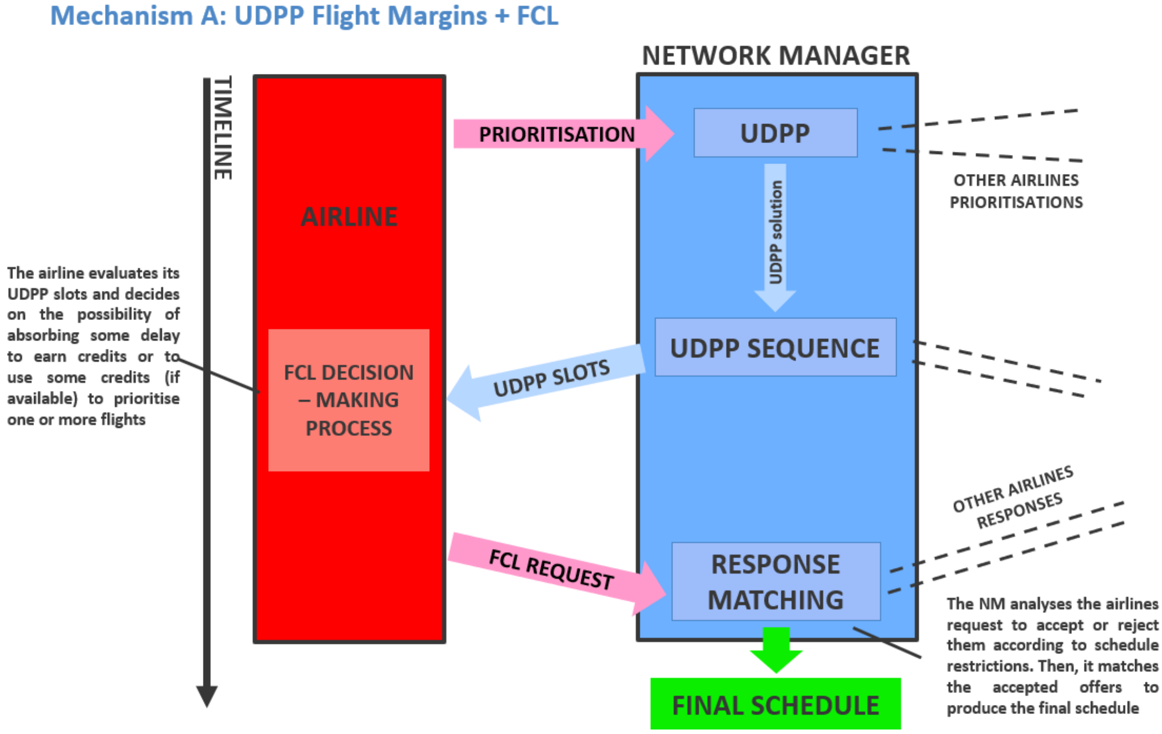

Figure 2. Mechanism A.

Advantages

Margins information can easily be shared with the central point/operator (as opposed to the costs), and can ensure good flexibility as the margins are directly linked to operations. This could be flexible enough even for small airlines. Airlines can absorb some delay in exchange for credits to be used to protect an important flight.

Limitations

It is still not clear whether this mechanism would prevent the domination by very large AUs or not. There is a question of the initial endowment of credits, and the time cycle in which they can be used, and when they expire. A further issue is linked with the place of credit earning and consumption. If credits are transferred between airports and the 'cost' of using a slot varies with demand (i.e., more credits needed in 'desirable' airports), then LVUCs might still be penalised as they'll have fewer credits to use at congested hubs w.r.t. main airlines operating at the airport. There is also the question of how to manage the changes in the schedule and its impact on airport capacity - it might make the gains of slot swapping useless or even make the situation worse if airport resources are not taken into account.

Barriers to implementation

The notion of credit needs to be defined - what it is, how they are earned, spent, when do they expire, fairness, if they can be earned in one place and spent in another. There are also concerns regarding security of priority / cost data being accessed/ inferred by others.

UDPP – Flight Margins (FM) + Centralised Slot trading

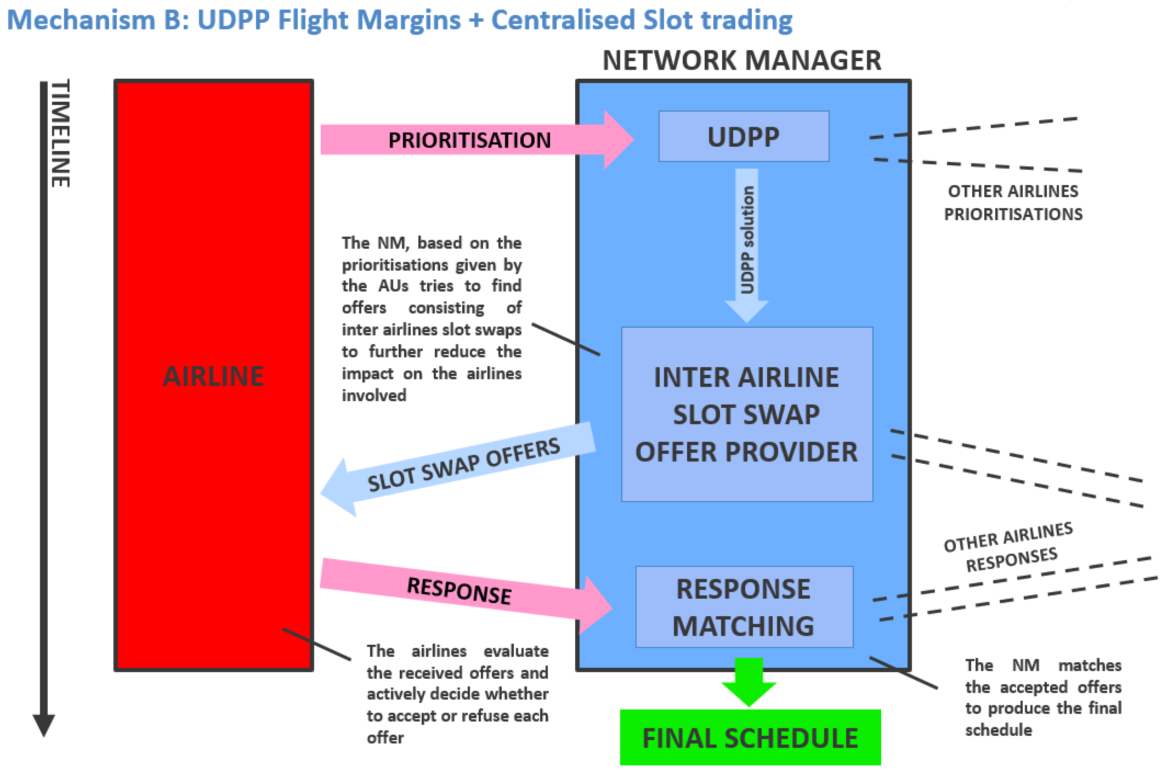

Figure 3. Mechanism B.

Advantages

The centralised approach has the following advantages: has a system overview as all requests are collected and evaluated by one, central, fair actor; the airports can have greater predictability of the changes that will occur in the schedule by maintaining active communication with the central player (NM for example), which in the end is solely responsible for the trading offers to send to the airlines; there is only one counterparty (NM); could reduce workload by small AUs; lower workload when compared to de-centralised approach.

Limitations

This mechanism might induce workload for airlines to review the slot swap offers and decide, as the airlines would like to have the final word in these decisions. Depending on how it is designed, the mechanism could be (semi) automated, which could reduce the workload by airlines. Equity needs to be introduced.

Barriers to implementation

The costs of supporting this process are not negligible, supposing the central party (NM) would shoulder the costs, as benefits could be significant enough across the board. Also here, there are concerns regarding security of data being shared. Some airlines might not have enough people to participate in the decision process.

UDPP – Flight Margins (FM) + Decentralised Slot trading

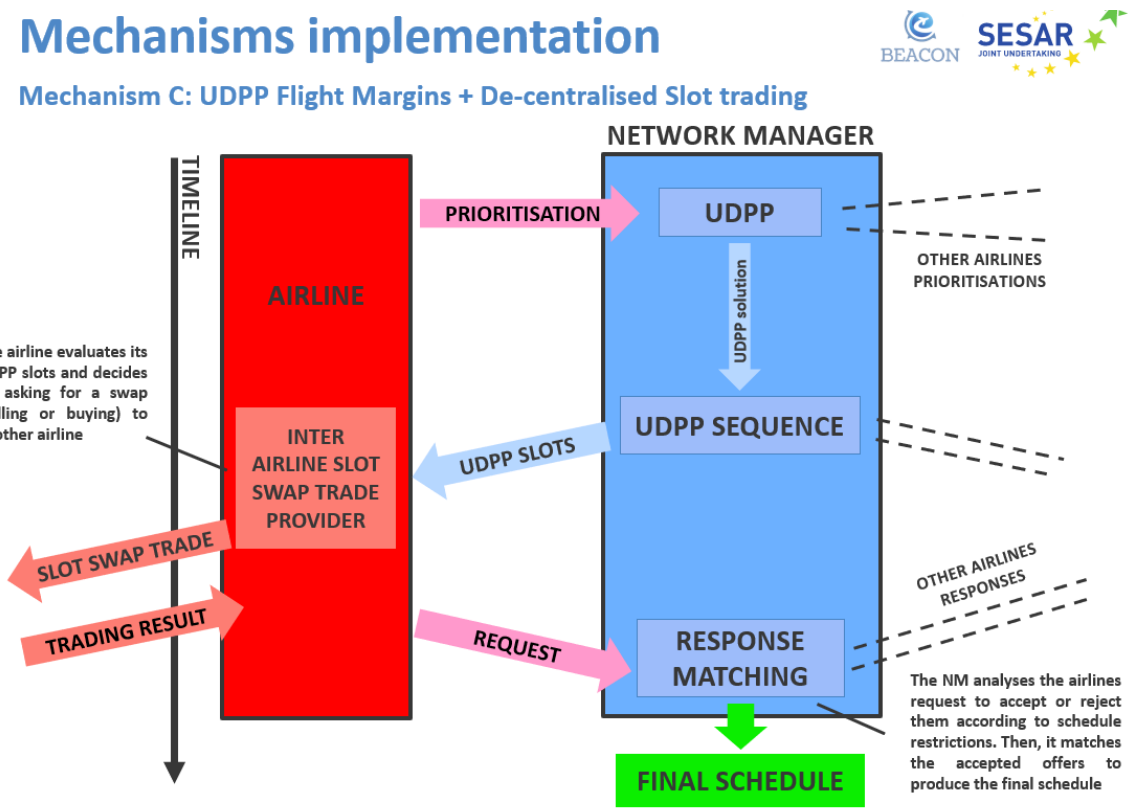

Figure 4.Mechanism C.

Advantages

Flexible, and no need to communicate preferences. Could be quicker to implement as it would be implemented on a commercial, not political side.

Limitations

Decentralised slot trading would mean high workload for airlines, which has to be minimised as much as possible for the airlines (otherwise nobody will have time to use it). Then there is the question of how to ensure equity if it is not ruled by a neutral instance? Issues of information sharing with other stakeholders (airports and ANSPs) as they need to be aware of decisions to provide needed services. AUs would likely need bilateral contacts.

Barriers to implementation

Not every AU would have manpower to run the process. The setup of the decentralised, commercial broker could be slow, and it will raise concerns on data security. Decentralised solutions might end up improving some local situations, but not necessarily the system-wide benefits would be accrued.

Primary auction

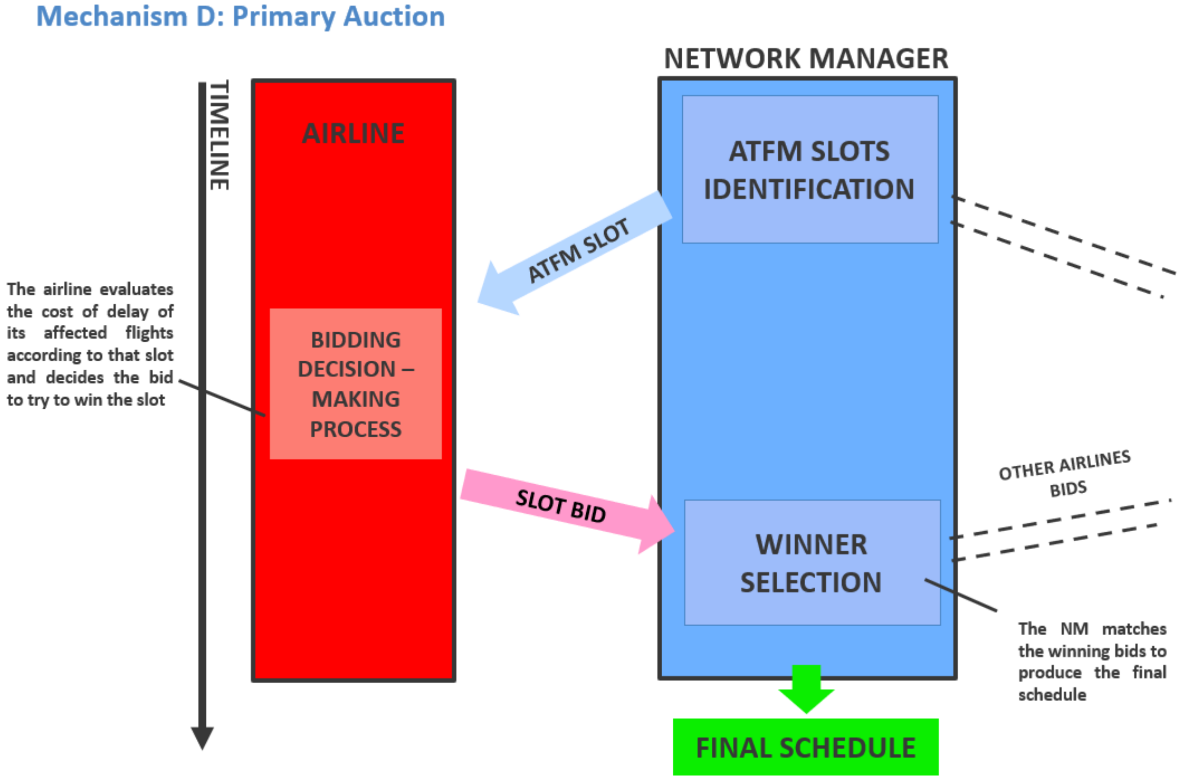

Figure 5. Mechanism D.

Advantages

The process is simple and fairly transparent, gives complete flexibility to airlines. However, there are questions on ensuring the fair credit transfers from one hotspot (airport of ANSP) to another one; or integration of airports in terms of feasibility of solutions when superimposed on airport resources.

Limitations

It is likely that big airlines will be advantaged as they have more resources to commit to auctions.

Barriers to implementation

A big investment in a software to automatise the process would be needed. The change of mindset would also be needed, at the moment it is likely the AUs would oppose. NM, airports and ANSPs should be involved to facilitate/support the auction system.

Other considerations:

Trajectory

It is not clear how are trajectories taken into account when deciding about the allocation of a slot. If the flights are swapped without NM being involved on destination, and airspace, it would be difficult to keep the network efficient. It seems that NM should always be involved in the process.

Mechanism implementation matters

For all mechanisms, airlines need either to have limited OPS, or to have a decision support tool to help them calculating the margins and priorities of the flights. Further, confidence issue for AUs if the system is highly automated cf. effort required to keep updating preferences.

Fairness/equity between airlines is a key concern.

Currently, the NM issues slot improvement messages every few minutes. The timeline on the usefulness would be to declare which flights to leave alone and which not - a day before.

A2. Discussion 2 Chains of decisions

The discussion revolved around important decisions during dispatching (and execution), and specification of the information needed to make the decision (or the information that triggered the decision).

Group in room A wrote down the detailed descriptions of decisions or events, that can be found in Table 4 and Table 5. The group in room B focused on discussions, and the summary of the discussion can be found in the Room B section.

Room A

Table 4.Decision or events during aircraft dispatch, part 1.

Decision /event	Perform a flight swap	Use inter-modality options (e.g., train, bus)	Reallocate passengers to a new flight
Decision description	An airline has 2 or more flights affected in a regulation and flight swap can be performed	When there are recurring events (e.g., wind at an airport causing diversions, ANSP strikes) agreement with bus or train companies are triggered to transfer pax	Passengers can be either rebooked or put in an hotel for the night

Information used in decision	Cost of delay of each one of the flights affected -passenger connections, -number of passengers impacted, -crew rotations, aircraft rotations, -possible maintenance event...etc	Cost of using other modes versus pax satisfaction	Depending of the pax status, number of connections, assistance required, alternatives existing, it will influence the decision Cost of accommodation, cost of rebooking
Other comments	Where do we include the BE? Within the cost of delay calculation? Many factors are estimated in first order quantitatively e.g. as time to implement, capacity of alternative option, pax satisfaction loss etc .... then all translate ultimately into cost, of course, but primary BE effect is in the non-cost domain	Trade-off in pax satisfaction between the inconvenience of changing transport mode and have a reduced (or no) delay at destination. Maybe BE may help in modelling how pax would decide if they were given the option?	May depend on the type of passengers? Depends on sophistication of AU system (e.g. for automated recovery options)

Table 5. Decision or events during aircraft dispatch, part 2.

Disruption Decision /event	Reallocate passengers to a new flight	Airport closure for the short time period	Fuel uptake (prior to push-back)	Diversion	Whether to hold (wait) a flight or not (e.g. late pax / crew)
Decision description	Passengers can be either rebooked or put in an hotel for the night	What to do with flight, passengers, crew etc. Cost of delay / cost of recovery options		Land at not final destination airport	Need to evaluate pax connections & delay recovery & crew duty time

Information used in decision	Depending of the pax status, number of connections, assistance required, alternatives existing, it will influence the decision Cost of accommodation, cost of rebooking	Crew duty times, number of pax, their connections, availability of aircraft, curfew later on during the day	Route and possible delay recovery options	Fuel on board, situation in neighbouring airports in terms of weather and availability of services Depends also of: - if DIV is technical, which maintenance services do you have, -is it a country requiring certain visa ...etc (for Pax), -weather complexity for pax reaching their destinations, - ...etc	Difficulty to estimate downstream effects (network propagation); also any effect of curfew at end of day
Other comments	May depend on the type of passengers? Depends on sophistication of AU system (e.g. for automated recovery options)	Very chaotic situation normally results in not the best decision without using the right tools		Pax specifics ie. final destination for transit pax	

Room B

Decision-making by dispatcher

The main decisions by dispatchers are to save on extra-costs. The main tool is the flight punctuality. There are a lot of intangibles in the decision making - “political” aspects (i.e. a minister on board, the flight has to be on time). The goal is also to come back to the schedule as soon as possible.

The dispatch has a lot of liberty - they do not have a set of hard rules, and it is not always easy to know what monetary impact it will have, thus they try to minimise the impact on passenger journey.

It is not easy to compare the effectiveness of two dispatchers. There are assessments, but as there are no hard rules, it is rather high level.

An example of a situation. An airline receives a 15 minute delay slot if they retain the trajectory at FL360. If they plan different trajectory, they are on time, but at FL250 - with this, the punctuality is maintained, but it increases the fuel consumption. This decision brought more costs, but maybe overall it was good if there were passengers that had to arrive on time. As the image of the company is very important, and the punctuality/regularity is a major part of the image, the keeping punctuality (even at cost) is considered as a good decision.

The dispatchers have access to different tools to guide their decisions - like crew, weather, ATC. However, they are not merged to one tool - the dispatcher accesses the information, processes it and comes to a decision. They have to reach the decision about 40 minutes before the go, as it is the time it takes to inform all the parties involved in the execution of processes prior to flight off-block time.

Airport processed impacted by ATFM slots

The decisions are taken on distribution of resources at the airport - gates, handling staff, etc. The more congested the airport, the harder it is to handle “quick” changes. If they know about the delay early enough, it is easier to adjust.

For example, swapping two flights as the airline wants to avoid missed connections. That is understandable and makes sense from airline point of view, but airport resources should be taken into account, especially if two flights are not the same aircraft type (as the gate might not be available), or coming from the same zone (i.e. Schengen vs other - as the processing might introduce delays at the airport).

Airports are not involved in the decision-making in the UDPP, but should be from informational point of view, to be able to make airlines understand that the swap should be such that the airport can actually serve the flights according to a doable plan that involves available gates, respecting connection times, etc. For example, if a gate is not available, a flight might lose more time on ground waiting for the gate than what they could have gained from the swap.

On the other hand, if everyone is aware of the resources, the decisions taken can unfold perfectly, which is what everyone would like, and that is the reason the APOC should be involved, to be able to share the availability of resources in the UDPP process.