D3.1 High-level modelling requirements

Deliverable ID:	D1.1
Dissemination Level:	PU
Project Acronym:	BEACON
Grant:	893100
Call:	H2020-SESAR-2019-2
Topic:	SESAR-ER4-08-2019
Consortium Coordinator:	University of Westminster
Edition Date:	26 March 2021
Edition:	01.00.00
Template Edition:	02.00.02

Authoring & Approval

Authors of the document

Name/Beneficiary	Position/Title	Date
Gérald Gurtner / UoW	Project Coordinator	18/12/2020
David Mocholí/ NOM	Project Team	18/12/2020

Reviewers internal to the project

Name/Beneficiary	Position/Title	Date
Nadine Pilon / EUROCONTROL	Project Team	23/12/2020
Madeline Quinlan / Salient	Project Team	23/12/2020
Marie Carré / SWISS	Project Team	23/12/2020
Lorenzo Castelli / UNITS	Project Team	23/12/2020

Approved for submission to the SJU By - Representatives of beneficiaries involved in the project

Name/Beneficiary	Position/Title	Date
Gérald Gurtner / UoW	Project Coordinator	30/08/2020

Rejected By - Representatives of beneficiaries involved in the project

Name/Beneficiary	Position/Title	Date
N/A		

Document History

Edition	Date	Status	Author	Justification
00.00.01	18/12/2020	Draft	Gérald Gurtner and David Mocholí	Initial draft for internal review
00.01.00	15/01/2021	Submitted to the SJU for approval	Gérald Gurtner and David Mocholí	Version for SJU delivery
01.00.00	26/03/2021	SJU feedback incorporated	David Mocholí	Corrected version for SJU delivery

Copyright Statement

BEACON

BEHAVIOURAL ECONOMICS FOR ATM CONCEPTS

This Technical Report 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 document provides all the necessary high-level modelling requirements needed for the proper development of the BEACON project. Firstly, it defines an assessment framework for the performance evaluation of the different flight prioritisations mechanisms selected. The suggested framework is based on a combination of desk research and consultation with different air traffic management (ATM) stakeholder representatives.

Secondly, it provides a detailed and exhaustive review of the flight prioritisation and trajectory allocation mechanisms proposed in the literature, ultimately identifying and selecting a final set of promising concepts to improve the performance of the ATM system in situations of demand-capacity constraints, to be included in BEACON simulations.

Finally, it describes the different variables and parameters that are part of the possible simulation scenarios and selects the potentially most interesting combinations to measure the performance of the proposed prioritisation mechanisms.

Table of Contents

List of Tables

List of Figures

1 Introduction

1.1 Scope and objectives

BEACON's general goal is to design new procedures for airspace users (AUs) to better allocate their resources (aircraft, pilots, crew, and others) in case of disruptions and evaluate the proposed procedures through new methods and tools able to take into account complexities of AUs' behaviours introducing behavioural economic techniques (for example bounded rationality).

With that goal in mind, this document has three different purposes: (i) to define a set of relevant indicators and metrics allowing a comprehensive assessment of the impact of the different flight prioritisation and trajectory allocation mechanisms that will be proposed and simulated in the scope of the project; (ii) to provide a detailed and exhaustive review of the flight prioritisation and trajectory allocation mechanisms proposed in the literature, including both currently operationally active concepts and more futuristic approaches with the ultimate goal of identifying and selecting the most promising concepts to be simulated in the context of the project; (iii) to determine the scenarios to be considered in the small-scale modelling experiments of WP4 and the large-scale simulations of WP5.

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 presents an overall view of the SESAR Performance Framework and proposes a set of key performance areas (KPAs) and key performance indicators (KPIs) for the assessment of the flight prioritisation mechanisms under review.
- Section 3 provides a detailed and exhaustive review of the flight prioritisation and trajectory allocation mechanisms proposed in the literature and identifies a set of promising mechanisms elected to be modelled and evaluated within the project.
- Section 4 deals with the definition of the scenarios, corresponding to a particular configuration of the simulation environment and the exogenous variables of the model.
- Section 5 includes the reference documents and acronyms.

2 Performance Assessment Framework

The definition of a relevant set of indicators and metrics is essential to allow a comprehensive assessment of the impact of the different flight prioritisation and trajectory allocation mechanisms that will be proposed and simulated in the scope of the project. The proposed framework looks for maximum alignment with the SESAR Performance Framework, focusing on those Key Performance Areas that are considered more susceptible of being influenced by the application of different flight prioritisation mechanisms, but also adds some specific KPAs and KPIs that are considered relevant for the problem under study. Particular attention is paid to KPAs that have received less attention in previous studies, but are however considered essential for the evaluation of flight prioritisation mechanisms, such as equity, fairness and robustness against unexpected Airspace User behaviours.

2.1 SESAR Performance Framework

Management of operational performance is executed in the scope of Single European Sky (SES) Performance Scheme. However, on the technology side, SES is supported by the Single European Sky ATM Research (SESAR) Programme, which provides advanced technologies and procedures with a view to modernising and optimising the future European ATM network.

In 2014 SESAR 2020 was launched alongside with an updated SESAR 2020 Transition Performance Framework which is the performance-driven development approach applied within the technical pillar of the European Commission's SESAR programme. It represents a framework to support the goal of ensuring that the programme develops the operational concept and technology needed to meet the performance ambitions described in the 2015 edition of the ATM Master Plan. It comprises the SESAR 2020 Performance Driven Approach; the framework of metrics (Key Performance Areas, Key Performance Indicators, etc.); and how these contribute to the overall European performance context.

SESAR Performance Framework follows a performance-based approach for development and deployment of operational changes and enabling technology. The selection of performance areas for SESAR 2020 reflects this and is consequently different from performance areas and metrics used in the regulatory arena (e.g., SES Performance Scheme) or in air navigation service (ANS) performance management (e.g., by air navigation service providers (ANSPs) monitoring and tracking performance). A key reason is that some metrics are easy to measure in operational or regulatory environment (e.g., delays) but very hard to assess in the development phase or when planning deployment. The selection of KPAs used as reference are the set of KPAs defined in ICAO framework with refinements to support SESAR requirements. These are: Safety, Security, Environment, Capacity, Predictability/Punctuality, Cost Efficiency, Flexibility, Civil-Military Cooperation and Coordination, Human Performance and Access/Equity [4].

Table 1. SESAR Performance Framework

KPA	Definition	Operational focus area
Environment	Addresses the management and control of environmental impacts, aiming to reduce adverse environmental impacts (average per flight).	• Fuel Efficiency • Noise impacts • Local Air Quality (LAQ)

Capacity	Addresses the ability of the ATM system to cope with air traffic demand (in number and distribution through time and space). It relates to the throughput of that volume per unit of time, for a given safety level.	• Airspace Capacity • Airport Capacity • Network Capacity • Resilience
Predictability and Punctuality	Addresses the ability of the ATM system to ensure a reliable and consistent level of 4D trajectory performance.	• On-time operation (Departure Punctuality, Arrival Punctuality) • Knock-on effect • Predictability
Cost Efficiency	Addresses the direct gate-to-gate ANS cost and the Airspace User costs.	• Direct gate-to-gate ANS cost • Direct Airspace Users cost • Indirect costs
Flexibility	Addresses the ability of the ATM system and airports to respond to changes in planned flights and mission. It covers late trajectory modification requests as well as ATFCM measures and departure slot swapping.	• Non-scheduled traffic • Trajectory modifications • Military airspace requirements • Impacted trajectories
Human Performance	Addresses the human capability to successfully accomplish tasks and meet job requirements.	• Human role consistency versus capabilities • Technical systems, and team structure support performance • HP transition factors
Access and Equity	Addresses the ability of the ATM system to assure that possible gains, raised from a SESAR solution, benefit all stakeholders in the same manner and no significant overall detrimental impact on the ATM system is produced.	• Fairness • Access • Transparency

2.2 BEACON Performance Framework

From all the KPAs proposed in the SESAR Performance Framework [4], only some of them are included in the BEACON assessment framework to evaluate the performance of the selected prioritisation mechanisms.

Considering the different perspectives of the stakeholders, which take part in the air traffic demand-capacity management, a pre-selection of the most suitable and necessary KPAs and indicators has been made. The industrial partners of the consortium, as well as the Advisory Board, will be at the centre of the validation process of these selected metrics and indicators.

The proposed KPAs are the following:

- Predictability and Punctuality
- Flexibility

- Access and Equity
- Fairness
- Cost Efficiency
- Robustness (to capture possible undesired effects coming through the simulation of the mechanisms under 'non-rational'[1] airline behaviours)

This pre-selected set of KPAs was discussed in several working sessions and the following conclusions were drawn:

- The Flexibility KPA understood as "the ability of the ATM System and airports to respond to changes in planned flights and late flight plan (FPL) request (non-scheduled traffic)" was recognised to be not relevant for the performance measurement of the prioritisation mechanisms. However, the dynamics of the prioritisation processes due to network uncertainty and AUs change of prioritisation is within the scope of BEACON and will be measured with several metrics included in the finally selected KPAs.
- The definition of the Access KPA was clarified. It is understood as the ability of airlines to make use of the different solutions implemented by SESAR. For example, if a certain prioritisation mechanism requires decision support software, this KPA would measure the degree of access of each airline to that technology. Under this definition the Access KPA falls outside the scope of the BEACON project.
- The punctuality metrics regarding flight delay should be aimed at measuring arrival delay (more important for airlines than departure delay). Some predictability metrics can be included to measure for instance the delay variance across the network. Additionally, some other passenger-centric indicators can be included: missed connections, modified itineraries, etc.

Thanks to this feedback, the final selection of KPAs to be included in the performance assessment framework can be consolidated. In addition, a series of metrics have been identified within each of these areas. The list of metrics, however, could be extended throughout the project as the implementation of the prioritisation mechanisms develops during WP4 and WP5.

2.2.1 Predictability and Punctuality

The predictability and punctuality are merged in one KPA in the SESAR Performance Framework 2018 due to the high inter-dependencies between each other. Metrics to measure how different mechanisms affect this area are essential from all the stakeholders' perspectives.

From an airline point of view, it is crucial to measure if a certain prioritisation mechanism increases the punctuality of its flights and, more generally, has an influence on the temporal quality of ATM

[1] All the airlines' decisions are taken by humans and people can be, in many occasions, subject to cognitive biases that can alter their decisions and make them deviate from purely rational solutions. For instance, due to the endowment effect (bias to overvalue certain items already owned) some AUs will be less likely to trade 'their' slots at a 'fair' value. To tackle this issue, BEACON will consider Behavioural Economics, which presents a considerable opportunity to advance the quality and rigour of simulation models, by delivering essential understanding of human behaviour and decision-making fed by several disciplines.

service aspects. For the airports, the importance of measuring predictability and punctuality resides in the fact that higher predictability levels allow the airport to fully utilise its current capacity. Finally, the Network Manager perspective relates higher predictability to a better demand and capacity balance.

Table 2. BEACON punctuality metrics

Metric	Unit	Calculation	Baseline
% Flights departing with +/- 3 minutes of the scheduled departure time	%	% Departures so that |AOBT – SOBT| < +/- 3 min. Difference in actual departure time vs. scheduled time due to ATFM causes	Derived from SESAR KPI PUN1
Flight departure delay	Minutes/Flight	Total flight departure delay in minutes divided by the number of flights departing from a particular airport or group of airports	-
Flight arrival delay	Minutes/Flight	Total flight arrival delay in minutes divided by the number of flights arriving from a particular airport or group of airports	-
Pax arrival delay	Minutes/Pax	Total passenger arrival delay to final destination in minutes divided by the number of passengers in a particular airport or group of airports	-

2.2.2 Equity

For the SESAR User Drive Prioritisation Process (UDPP) programme, equity is the main constraint. It includes the idea by which the actions of one AU must not negatively affect (significantly) other AUs' flights. This supposes an essential requirement from the airline's perspective. This demand is in accordance with the vision of the Network Manager, who finds essential that any prioritisation mechanism does not systematically favour or penalise any flight or AU, demonstrating the need to measure this property in possible future prioritisation mechanisms.

Table 3. BEACON equity metrics

Metric	Unit	Calculation	Baseline
Change in AU's delay or cost compared with other AUs	%	Difference in delay (or cost) of the AU concerned divided by the total difference in delay (or cost) of all the AUs together between the Solution Scenario and the Reference Scenario[2]	Derived from SESAR PI EQUI1

[2] The Reference Scenario corresponds to the simulation of the current concept of operations, the FPFS mechanism plus a limited swapping capability, which is understood as "acceptably equitable" and fair", in the sense it preserves the original order of the sequence.

Change in AU's delay or cost per flight compared with other AUs	%	Difference in delay (or cost) per flight of the AU concerned divided by the total difference in delay (or cost) per flight of all the AUs together between the Solution Scenario and the Reference Scenario	Derived from SESAR PI EQUI1
AU total delay or cost relative to baseline AU total delay	%	AU total delay (or cost) in the Solution Scenario divided by the AU total delay (or cost) in the Reference Scenario	SESAR PI EQUI5
Number of flights advantaged and/or disadvantaged	No.	Number of flights impacted (+ or -) by a certain change (Difference between delay and cost)	SESAR PI EQUI4

For reference, SESAR equity PIs below [4]:

PIs	Unit	Calculation	Mandatory
EQUI1 Net Difference in Au's Delay or Cost Compared with other AUs	+/-%	Change in Delay (or Cost) of the AU concerned / Total Delay (or Cost) of All the AUs	NO
EQUI2 Relative Advantage Gained by one AU over the Others weighted by impacted flights	+/-%	Change in Delay (or Cost) of AU1 divided by Number of Movements of AU1 / Change in Delay (or Cost) of AU2 divided by Number of Movements of AU2	NO
EQUI3 Total ATM Delay per AU relative to Baseline ATM delay per AU	+/-%	Total delay (per airspace user) in the Solution Scenario / Total delay (per airspace user) in the Reference Scenario	NO
EQUI4 Number of Flights Advantaged and/or Disadvantaged	No.	Number of Flights impacted (+ or -) by the change	NO
EQUI5 AU Delay per Flight Compared to Baseline	%	Delay per Flight of AU concerned in the Solution Scenario / Delay per Flight of AU concerned in the Reference Scenario	NO
EQUI6 AU cost per Flight Compared to Baseline	%	Cost per Flight of AU concerned in the Solution Scenario / Cost per Flight of AU concerned in the Reference Scenario	NO

Figure 1. SESAR Performance Framework equity metrics

2.2.3 Fairness

Fairness can be defined as the quality of distributing something among a set of individuals in a manner, not necessarily evenly, such that each receives a share that fulfils its individual satisfaction threshold [5]. In order to measure fairness objectively, it is essential to agree on a common way to quantify such individual satisfaction thresholds. This could be confused with the definition of equity. However, equity as described above, only measures how uniformly the distribution of the costs (or delay) is performed, i.e., without taking into account individual satisfaction thresholds. In other words, the equity measures how uniformly the absolute cost impacts are allocated among AUs and the fairness measures how uniformly the relative cost impacts are allocated among AUs (relative with respect their tolerable cost penalty thresholds).

The fairness metric proposed here is the one defined in [5]. In particular, the fairness metric among K Airspace Users, measures how balanced the relative overall cost penalties are distributed among different airspace users operating in the scenario, considering as a reference the Cost Penalty Threshold for each flight, and accounting only the set of flights interacting in such scenario.

Table 4. BEACON fairness metrics

Metric	Unit	Calculation	Baseline
Balance of the overall cost penalties distributed among the AUs	[0,1]	Ratio of the geometric mean divided by the arithmetic mean of AU satisfaction (i.e., 1-ρ_i)[3]	[5]

2.2.4 Cost Efficiency

The Cost Efficiency KPA is closely related to the delay airlines face in their operations and how they manage it. From this perspective it is essential to measure if a certain prioritisation mechanism is able to provide effective tools to decrease the costs associated with the imposed ATFM delays. A better configuration that allows airlines to adjust their operations in a cost-efficient way also has a positive impact on airports, which can see their income increase due to the greater attractiveness of the system.

The SESAR Performance Framework distinguishes two main focus areas inside this KPA. The first cost impact considered is the direct gate-to-gate ANS cost, and the second cost impact area is the Airspace User costs. Following the objectives of the project we will restrict our vision to the AUs cost, which refers to cost efficiency obtained by AUs other than gate-to-gate ATM costs. This particular area may include benefits noted in other metrics, especially when considering efficiency benefits, however, these already measured benefits should not be included, to avoid double-counting of benefits.

[3] ρ_i is the aggregated relative cost penalty for an Airspace User. The calculation can be found in [5].

Table 5. BEACON cost efficiency metrics

Metric	Unit	Calculation	Baseline
Per-flight direct cost	EUR/Flight	Impact on direct costs related to aircraft and passengers: fuel, staff expenses, passenger service costs, navigation charges, strategic delay[4]	Derived from SESAR PI AUC3
Per-flight cost of delay (tactical)	EUR/Flight	Cost of delay[5] of each flight. This can be aggregated by airline	-

2.2.5 Mechanism robustness

The main ambition of this project is to develop a new methodology for assessing user-driven prioritisation mechanisms following the paradigm of Computational Behavioural Economics. While classical approaches require the use of rigid assumptions such as perfect rationality and complete information, Behavioural Economics allows these assumptions to be relaxed at the time of evaluation. This entails an enormous advantage to test situations where AUs behave in a "non-rational" or strategic manner, which is the case most of the time.

The robustness of each mechanism will be measured by comparing a baseline “perfectly rational” situation with other simulations where the behaviour of the AUs is modified to simulate “non-rational” practices. The metrics belonging to each of the previously selected KPAs are calculated and the difference between the values for both behavioural scenarios is computed. The smaller the difference in the metrics, the greater the robustness of the mechanism to non-rational decision-making. The table below shows how the robustness indicators are developed. For simplification purposes, only one metric per KPA is represented.

Table 6. BEACON mechanism robustness metrics

Metric	Unit	Calculation	KPA Addressed
Change in % of flights departing within +/- 3 minutes of the scheduled departure time	%	Difference [%] between the resulting % of flights departing within +/- 3 minutes of the scheduled departure time computed first in a perfectly “rational” scenario and later in a scenario with AUs “non-rational” behaviours.	Predictability and Punctuality
Change in AU total delay relative to	%	Difference [%] between the total delay (per AU) in the solution scheme divided by the total delay (per AU) in the baseline scheme	Access and Equity

[4] Due to the tactical nature of the simulation model being developed, the strategic delay will be considered as given, as the model will take as input a predefined flight schedule. Consequently, the minutes of strategic delay potentially saved by a certain mechanism will not be measured.

[5] Cost of delay calculated based on University of Westminster (UoW) reference values (European airline delay cost reference values report, version 4.1) [7].

baseline AU total delay		computed first in a perfectly "rational" scenario and later in a scenario with AUs "non-rational" behaviours.	
Change in cost of delay per airline	%	Difference [%] between the cost of delay per airline computed first in a perfectly "rational" scenario and later in a scenario with AUs "non-rational" behaviours.	Cost Efficiency

3 Flight prioritisation mechanisms selection

The task of selecting the prioritisation mechanisms required a detailed and exhaustive review of the flight prioritisation and trajectory allocation mechanisms proposed in the literature, including both currently operationally active concepts and more futuristic approaches. The ultimate goal is to identify which of the examined mechanisms are the most promising to improve the performance of the ATM system in situations of demand-capacity imbalance, and select the mechanisms that will be simulated in the context of the project.

3.1 Current concept of operations

3.1.1 First Plan First Served (FPFS)

In Europe, every time an imbalance between the demand and capacity is detected, the ANSPs propose and agree an imposition of a regulation with the Network manager (NM) [6]. The regulation is limited in space and time and has a capacity limit that should be respected. The regulation is imposed in the form of the assignment of take-off delays to the flights scheduled to pass through the space/time affected by it, the so-called ground delays. Currently, the assignment of the new departure time slots, Air Traffic Flow Management (ATFM) slots, is performed following the First Planned First Served (FPFS) principle. This means that the NM sequences the flights according to the flights' Estimated Time Over (ETO) the specific sector, point, or airport. The FPFS policy has been accepted and deployed for many years, as it ensures a good trade-off between simplicity and capacity management and is perceived by the AUs as a fair policy because it preserves –whenever possible– the original order of the sequence (Vossen and Ball, 2006). However, it does not minimise the total cost of the delay, as there might be flights for which the same amount of delay generates different costs for Airspace Users (AUs) or passengers, connecting flights being an obvious case [7]. In order to overcome this drawback, since the mid-1990s, AUs have been allowed to exchange ATFM slots between flights affected by the same regulation. However, the flexibility provided by this mechanism was rather limited as only one swap per flight was allowed and swaps across airlines were not considered.

3.1.2 SESAR UDPP Step 1

The lack of flexibility provided by the FPFS system has a significant impact on airlines' annual costs and revenues. SESAR is tackling this problem through the development of the UDPP programme. The objective is to provide additional flexibility to the AUs for readjusting their operations in a more cost-efficient manner in the presence of unforeseen demand and capacity imbalances that require the application of delays to flights. The UDPP research is framed in the scope of the Collaborative Decision Making (CDM) philosophy, which aims to involve all the stakeholders in working more transparently and collaboratively, exchanging relevant accurate and timely information. It represents the backbone of the UDPP concept. Early UDPP developments in Step 1 introduced Enhanced Slot Swapping (ESS) and UDPP Departure (DFlex).

3.1.2.1 Enhanced Slot Swapping (ESS)

The Enhanced Slot Swapping (ESS) mechanism is intended to enhance the current slot swapping procedure by means of improving the flexibility to react to imposed delay. The main objective is the introduction of enhanced slot swapping capabilities to extend the use of the prioritisation mechanism between airlines affected by ATFM delays. The process for submitting slot swapping request has been greatly improved to be more visible and user-friendly. At the same time, EUROCONTROL and the NM agreed to open it to swap across airlines, provided prior bilateral coordination. In addition, Airspace Users have proposed improvements to the slot swapping rules: the ESS principle can be subdivided in several concept, "features", which are smaller, independent operational improvements (SESAR Step 1 V3 UDPP Validation Report, 2015), defined with airspace users.

- **ATFM Pre-Allocated Slot Swap**: This concept provides AUs with the option to pre-allocate an ATFM slot to a flight 'A', in order to swap it with a flight 'B', which is already in slot-issued status. The flexibility provided by this mechanism overcomes the strict requirement imposed by the previous system to only swap issued slots. This upgrade appears of great importance when there is a need to exchange slots in advance due to the earlier Calculated Take-Off Time (CTOT) of one of the flights. However, it has not been accepted (and not implemented) on the NM side due to the risk of reducing the flexibility of the slot allocation process.
- **Multi-Swap of ATFM Slots**: This principle provides AUs with the flexibility to swap slots multiple times between flights sharing most penalising regulation. Either the flight can be improved in several independent swap requests, or in several consecutive steps in the same swap request. This request from AUs was finally limited to "up to 3 swaps per flight" to limit the variability close to departure.
- **Substitution on Cancellation**: This mechanism allows AUs to cancel a flight and instantly assign the free slot generated to another of its flights. The flight that takes the empty slot is termed promoted flight and must have the same most penalising regulation as the cancelled flight. The empty slot created by the promoted flight is given back to the NM to fill with another flight. This concept follows the "Ration-by-Effort" (RBE) principle.
- **Most Penalising Delay**: With this system AUs are allowed to swap flights that depart from the same Collaborative Decision-Making Airport (A-CDM), with different most penalising regulation, if the delays generated by the airport exceed the most penalising regulation delays of the two flights in question.

According to the "SESAR Step 1 V3 UDPP Validation Report" Enhanced Slot Swapping (ESS) offers an estimated average benefit of 4900 EUR per swap. Additionally, the previsions for the ESS over 20 years are in the order of magnitude of hundreds of millions of euros [8].

Although not all features have been finally implemented, ESS it is being successfully deployed by EUROCONTROL since 2017. In fact, some of these features have been considered unacceptable from the point of view of the Network Manager, in charge of the network stability. For example, the Pre-Allocated feature: pre-allocated slots are very fluid - that's why they are not allocated yet -; if they are swapped with an allocated one, then either the swapped flight has no departure time anymore or the pre-allocated flight gets allocated much too early, thus freezing the possibility to improve the slot and to optimise the sequence later on. This would possibly lead to freezing the sequence if many such swaps happen: sub-optimal sequence, no flexibility to face sudden events that would modify the regulation.

3.1.2.2 UDPP Departure (DFlex)

SESAR UDPP Step 1 introduced another solution named UDPP Departure or DFlex for Departure Flexibility, for which maturity has been assessed as sufficient to support a decision for industrialisation.

Here, the ATM operational improvement comes from the extra flexibility provided in the departure swapping stage, which allows AUs in a Collaborative Decision-Making Airport (A-CDM) to change the priority order of unregulated flights among themselves and via the airport authorities.

Prior to the day of operations, the airport receives all the flight plans and sorts them by reference time. From this, a reference-time list is built, which is processed by an algorithm to define the Pre-Departure Sequence (PDS), and then allocate the Target Start-up Time (TSAT) with a retro calculation of the taxi-time. The UDPP Departure solution consists in re-prioritising the flights in the reference-time list, with a recalculation of the Pre-Departure Sequence and a new TSAT allocation. DFlex provides three different features for implementation (Release 4 Local SESAR Solution #57, 2015).

- **Departure Reference Time Reordering**: This mechanism provides the AUs the ability to reorder their flights in the reference-time list. The reordering procedure is only possible between flights belonging to the same group or alliance and needs to adhere to constraints such as Calculated Take-Off Time (CTOT), Scheduled Off-Block Time (SOBT) and Target Take-Off Time (TTOT).
- **First Priority for Departure**: The mechanism is similar to the Departure Reference Time Reordering, but here the AUs just request the prioritisation of one of its flights. The prioritized flight is promoted up while the rest of the AUs flights are cascaded down through the list. Again, constraints such as CTOT, SOBT and TTOT are respected by the PDS.
- **Upwards Cascade on Departure Cancellation:** This concept states that whenever an AU cancels a flight in a CDM Airport its remaining flights in the reference-time list are cascaded upwards.

The DFlex operational concept developed with Air France, FedEx, American Airlines and HOP!, has already been successfully implemented at CDG Airport, where important benefits have been measured [8].

3.2 SESAR UDPP Step 2

SESAR UDPP Step 2 took the search of the extra flexibility demanded by AUs a step further. It was conceived as new design for the ATM system whereas Step1 was supposed to be only “quick wins” on the current system.

AUs requested to receive notifications about the risk of regulations, SESAR created the notions of “imbalance” (risk) and “hotspot” (needed for a demand-capacity balancing measure). That is how UDPP allows AUs to reorder their flights before the regulation is frozen, or rather during the construction of the regulation. Three new mechanisms were proposed and consolidated in a meticulous process involving several AUs delegates (Air France, HOP!, the International Air Transport Association, SWISS, Air Baltic, ElAl, Transavia). The solutions that emerged from the detailed study were Fleet Delay Reordering (FDR), Selective Flight Protection (SFP), and Flight Margins (FM). The 3 features can be combined, and altogether aim to improve the control AUs will have in the future to adapt flight schedules in case of disruptions [8].

3.2.1 Fleet Delay Reordering (FDR)

The FDR is an operational concept which gives the AUs the ability to reorder their delayed flights in a hotspot. The airlines which acknowledge in advance the relative value or importance of their operating flights can submit a prioritisation list to the Network Manager, which will use it to reorder the departure sequence, according to these preferences, in the case a hotspot is declared. Reordering preferences is given assigning numbers from 1 to xxx, 1 being the flight with the highest priority. Letters B and S are used to respect the imposed Baseline delay (B) and to suspend (S) a flight, respectively [8].

The next figure illustrates a use case of the mechanism. The blue airline is impacted with four regulated flights, corresponding to the numbers 2, 4, 5 and 8, which are originally sequenced following the FPFS principle. Using the Fleet Delay Reordering mechanism, the airline delivers a prioritisation list, indicating its preferences, to the Network Manager. The submitted list reorders the flight slots according to their value for the airline, on this occasion the most important flight is number 8 followed by 4, 5, and 2. Finally, the resulting departure sequence submitted by the Network Manager follows the airline preference list respecting the constraint imposed by the original departure scheduled time of each flight, meaning that any flight can get a slot prior to their original departure time.

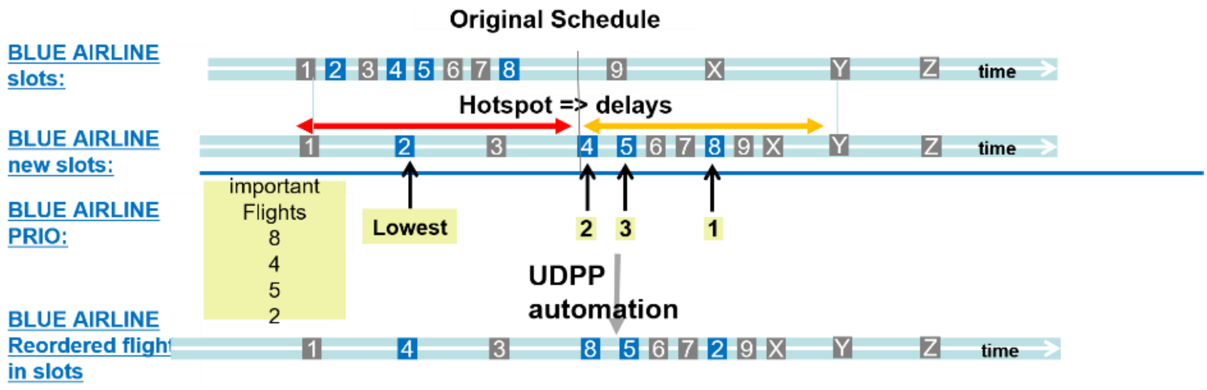

Figure 2. Fleet Delay Reordering (FDR) mechanism

3.2.2 Selective Flight Protection (SFP)

The SFP mechanism is a UDPP feature which provides AUs with the ability to protect their most valuable flight in a hotspot. It is very useful for situations where it is essential to bring a flight as close as possible to its original schedule, while respecting the rule of not departing before the original flight scheduled time. One use case is illustrated in the next figure for clarity. In the hotspot example, the blue airline owns two flights named 2 and 8. The value of both flights is significantly different, 8 being the most delayed flight, and the most important too. Accordingly, the affected airline decides to protect its valuable flight using the SFP UDPP feature. The mechanism is divided in two consecutive phases. The first step consists on directly swapping the ATFM slots of the two flights, on this occasion the slots corresponding to the flights 2 and 8 are switched. The second step readjusts the time slot of the prioritized flight, number 8, to match it as close as possible to its scheduled departure time, meaning that the protected flight will receive minimal delay and will depart almost on time. Additionally, due to the readjustment process, flights belonging to other airlines, number 3 and 4 here, are positively impacted by climbing a position in the final sequence departure, thus reducing their imposed delay.

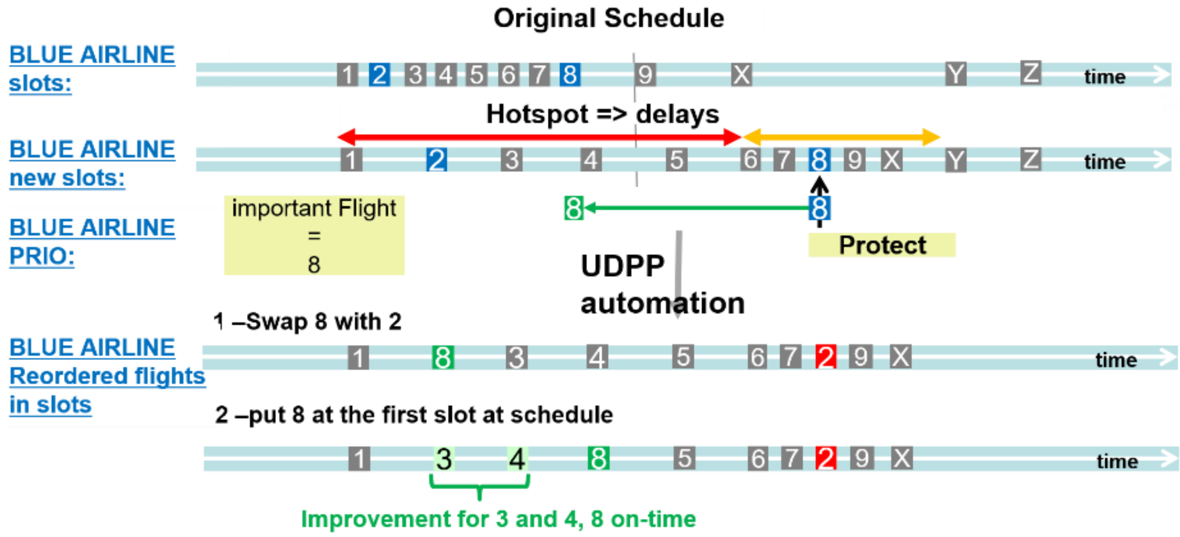

Figure 3. Selective Flight Protection (SFP) mechanism

3.2.3 Flight Margins (FM)

With this feature, airlines can directly use the operational margins of manoeuvre of each flight to automate the prioritisation of their flights. Airlines prioritising their flights aim to avoid breaching certain unwanted events (passenger transfers, compensations, crew or aircraft constraints, curfews) that drastically increase the cost of delay and nuisance to passengers and define their margins.

Airlines can provide for each flight involved in a hotspot its "*Time not before*" and "*Time not after*". Combined with a priority value (see FDR), these are used by UDPP to optimise the ordering of the flights in the slots of the airline.

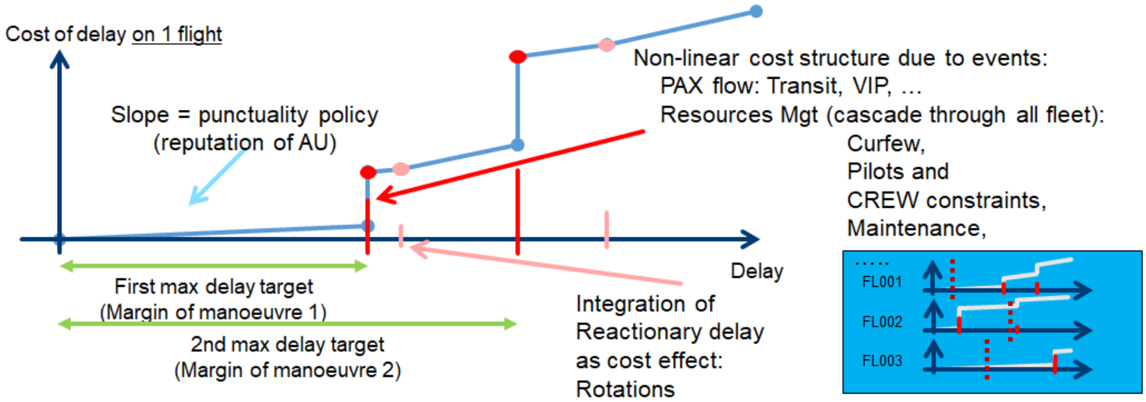

Figure 4. Flight Margins (FM) mechanism

3.3 Other approaches for user-driven slot and trajectory allocation

In addition to the concepts developed within the context of SESAR, a variety of allocation mechanisms have been investigated and proposed in the literature. The proposed mechanisms put the emphasis on the assignment of the ATFM time slots, on the priorities assigned to flights in case of disruption, on the potential rerouting paths, or everything at the same time. Depending on the operational nature underpinning the prioritisation concept, the different mechanisms can be divided into three groups. Firstly, the mechanisms concerning the implementation of several operational standards and regulations fall inside the **rule-based category**, which in general do not take into account costs in the optimisation process, only adherence to slots. Secondly, there are several mechanisms which rely on the use of money and the forces of supply and demand to determine the optimal solution in situations where different entities are competing for scarce resources: **monetary, market-based mechanisms**. Finally, and in part due to the reluctance of many AUs to use real money, some mechanisms make use of virtual currencies, such as credits, to carry out certain prioritisation strategies: **non-monetary, market-based mechanisms.**

It is important to note that not all the (potential) mechanisms are applicable for every stage of Air Traffic Flow and Capacity Management (ATFCM). Due to operational constraints, the use of some mechanisms is limited to several months in advance (strategic action), these being ineffective for disruptions on the day of operations (tactical action).

3.3.1 Rule-based mechanisms

3.3.1.1 Best Performing Best Served (BPBS)

In the context of the detailed study carried out by NextGen in flight prioritisation, a promising mechanism named Best Performing Best Served (BPBS) is proposed. The concept follows the rationale of providing priority to best performing aircraft in enhanced operations. The BPBS mechanism plays a double role, it encourages AUs to invest in new equipment and technologies, leading to prioritisation benefits, and at the same time helps to enhance the performance of the airspace system generating additional system capacity and improved airspace services.

The BPBS mechanism follows the philosophy of the Performance Based Operations (PBO). This concept relies in the idea that the airspace system should reinforce higher performance aircraft to fully exploit their performance capabilities. In fact, AUs are fully encouraged to embrace capabilities that improve the performance and capacity of the airspace system as a principal basis of the PBO concept. As a result, BPBS provides a significant contribution to the efficiency and performance of the airspace system.

As the opportunity to participate is made available to all operators that meet the criteria, BPBS offers high transparency and perceived fairness. For future applications the positive cost/benefit of BPBS operations to the airspace system overall, as opposed to local applications, should be confirmed. Also, the criteria for participation in BPBS and the effects of an application of BPBS on performance should be refined, as well as the required precision and performance for each element [9].

3.3.2 Monetary market-based mechanisms

Due to the intrinsic nature of the flight prioritisation concept, it appears fairly reasonable to consider some kind of market mechanism to define it. Previous studies [9] have concluded that market mechanisms are potentially suitable to contribute to the achievement of many of the targets set by NextGen and SESAR, while at the same time providing extra flexibility for AUs and improving the economic efficiency of the airspace system. Different market concepts have been proposed by researchers with the aim of optimising the ATFM slot allocation process.

3.3.2.1 Prioritisation by auction

In an environment as structured and constrained as the airspace system, auction processes appear to be (often) suitable for an equitable and economically efficient distribution of the scarce resources available. Accordingly, slot auctions can be conceived as primary or secondary depending on the bidding characteristics. In a primary auction the Network Manager is in charge to directly sell rights or priorities to AUs. Meanwhile, in secondary auctions the AUs are allowed to trade and exchange resources obtained in an initial allocation. Different type of auctions are proposed depending on the characteristics of the market.

- **Primary Auction**: A primary slot auction concept describes the process by which AUs compete for the scarce resources (ATFM slots) by offering them up for bid to an honest broker, the Network Manager, which then sells each item to the highest bidder. The auction could be conducted strategically during negotiation of 4D trajectories (4DTs) or in real time during flight (tactically), as the dispute over operating resources arises. In the case of a tactical primary auction. each ATFM slot is auctioned following the restrictions imposed by the scheduled departure time of the flights affected by the regulation, meaning that airlines cannot bid for time slots whose new expected of-block time (EOBT) is earlier than the original off-block time of the flight willing to take that position. The Network Manager would be the organism responsible for carrying out this type of auction.
- **Secondary Auction**: A secondary auction provides the participants with the ability to exchange valuable resources with possible side payments and also to buy and sell them. In the case of a slot auction, AUs are allowed to buy or sell ATFM slots within them. The inherent nature of a secondary market implies that a first allocation of the resources has been already performed, in the case of the ATFM slots this can be done following the current FPFS policy, i.e., according to the flights Estimated Time Over (ETO) the specific sector or airport. Then, due to the non-linearity of the cost of delay, some AUs may want then to purchase an earlier time slot in a regulation while other AUs may be interested in selling their slot receiving a compensation for the delay increase.

L. Castelli et al. (2011) [10] proposed a slot allocation mechanism based on market principles which enables AUs to pay for delay reduction or receive compensation for delay increase. The mechanism takes the FPFS allocated slots as the initial endowment of each flight and enforces the rule that no compensation is given for cancelled flights realising the slots, in order to avoid the creation of ghost flights just to make money. The proposed mechanism is distributed, meaning that it directly involves each airline in the decision process of the slot reallocation and does not require the disclosure of the delay costs, data which AUs are very reluctant to reveal. Additionally, it neither requires an external subsidisation to work, nor produces an economical benefit to be distributed outside the set of participants.

3.3.2.2 Centralized Peak Loading Pricing (CPLP)

This concept is based on the same ideas as the high-occupancy toll lanes used on toll roads where the variability of the price is used to control the demand. The final objective of this concept is to use a price mechanism to make AUs aware of the cost they produce when performing during a peak demand. This means, they should pay for the extra congestion they generate, encouraging at the same time the redistribution of the demand to less crowded options (in space or time). However, it is important to remark the fact that the congestion pricing approach is only useful for en-route capacity-demand imbalances, for regulations affecting airports capacity this mechanism finds to be useless and unreasonable.

For the use of terminal and en-route air navigation services, AUs are required to pay some charges to the European Air Navigation Service Providers (ANSPs). The en-route charges are fully dependant on the number of states crossed by the route path and can be simply computed as the addition of each single price to pay for passing over a state during the flight. The aforementioned national charge is equal to the product of the distance factor, the weight factor of the aircraft, and a national unit rate. With that in mind, T. Bolić et al. (2017) proposed a Centralised Peak-Load Pricing (CPLP) mechanism which allows to modulate en-route charges to prevent demand and capacity imbalances. The mechanism approaches the pricing concept in a centralised manner, defining a central authority which is responsible for setting en-route charges in the network. CPLP consists of two phases. Firstly, congested airspace sectors, related peak, and off-peak hours are detected. In the second phase, the central planner needs to adjust en-route charges in the network. Consequently, AUs react to the pricing strategy changing from expensive routes to cheaper ones, thus alleviating the congestion in both space and time. As unit rates are currently set once per year, the effect of the pricing mechanism is only evaluated at the strategic level, meaning that last-minute disruptions are not taken into consideration [11].

3.3.2.3 Route contracts

Route contracts also represent a suitable solution to mitigate the impact in terms of cost which AUs experience during capacity-demand imbalances. By signing, in advance, a route contract with the ANSP, the AUs agree on a minimum level of airspace operational services conforming with the limits, terms and conditions of the contract. These types of contracts can be of very different natures depending on the final objective pursued. Route contracts signed with the ANSPs can also be conceived as a first endowment to be exchanged in a secondary market [9].

Another promising use of route contracts for delay mitigation was illustrated in COCTA, a research project within SESAR Exploratory Research ER (H2020) program. It aims at improving efficiency as well as quality of air navigation service provision in Europe through better coordination of capacity and demand. The futuristic concept proposed by COCTA follows a change in the approach to capacity-demand management. It reinforces the figure of the Network Manager with the ability of having contractual relations with ANSPs and AUs. The Network Manager displays a dual role, being on charge of both the capacity definition, with the ANSPs (strategic and pre-tactical phase), and the demand management, with AUs.

On the capacity side, the Network Manager matches airspace capacity with expected demand by means of a network-centred and demand driven approach, in contrast to the current supply driven practice shaped as local (ANSP) traffic peaks. Consequently, excessive provision of airspace capacity is reduced, with associated cost savings. On the demand side, the Network Manager performs trajectory pricing offering different routing options to AUs. With this new paradigm, the AUs are not charged for the air navigation services by the sectors crossed but rather for the city-pairs they are flying. Therefore, there is no motivation now for the AUs to flight longer routes just to avoid high charging sectors, what brings in positive environmental benefits too.

AUs choose between different route packages, which are contractual permissions to fly within a given margin of spatial deviations from the shortest route between a city-pair. When AUs purchase this permission (in the strategic phase) they obtain the right to fly a route within these margins, however it is the Network Manager who decides shortly prior to departure (tactical phase) on which route exactly the aircraft needs to fly. The charges that the aircraft needs to pay for the flight permission depend on the margin of flexibility granted by the Network Manager, this being more expensive for the products with smaller margins - which means a route potentially closer to the desired one. The project results show that the COCTA approach allows the same traffic volume to be handled with 6% less use of capacity, with (up to) 83% fewer minutes of delay [12].

3.3.3 Non-monetary market-based mechanisms

Some stakeholders are reluctant to accept prioritisation mechanisms which involve using real money. Non-monetary market mechanisms, based on the use of a virtual currency, or credits, provide a good alternative. Credit mechanisms are often designed to allow AUs to participate, reflecting the value of their flights involved in an operation without explicitly divulging sensitive information regarding business strategies and costs of delay.

3.3.3.1 Flexible Credits for Low Volume Users in Constraint (FCL)

All the proposed prioritisation mechanisms are aimed at improving the flexibility by which AUs can change their operational strategies to minimise the impact of the delay (cost of delay) in case of disruptions. However, the majority of these allocation mechanism are ineffective when an airline has a low number of impacted flights (3 or less) in a hotspot, creating a situation of reduced flexibility or even no flexibility at all. Surprisingly, this situation is quite frequent, based on the analysis of all the European airport regulations in 20 consecutive AIRAC cycles, the proportion of Low Volume Users in Constraint (LVUCs) in daily hotspots is large, being more than 2/3 of the AUs typically affected by regulations [13].

The Flexible Credits for Low Volume Users in Constraint (FCL) (also known as Extended-SFP, ESFP) is a concept proposed in the scope of SESAR investigation on new prioritisation features. The potential advantage is the ability to also provide flexibility to AUs with a low number of flights involved in a regulation, thus increasing the equity and the access of the system. It is based on the use of a virtual currency without monetary value, named delay credits. The mechanism enforces minimum levels of operational feasibility providing a fluid communication and an efficient coordination between AUs. It is considered as an extension, or a complementary mechanism, to other UDPP features such as Selective Flight Protection (SFP).

ESFP follows a ration-by-effort principle, meaning that AUs can gain delay credits by accepting extra delay on their lower-priority flights, and then spend these credits to protect higher-priority flights. For instance, an airline with just one affected flight in a regulation could accept more delay when it is far from its operational margins and the disruption does not come with an excessive increment in cost; positively impacting other delayed flights in the hotspot. In exchange for the delay absorption, the AU earns some credit points which can be used in other or future hotspots to cut down the cost when one of its flights is impacted by important delay (beyond the operational margins). In order to tackle the LVUCs' lack of flexibility issue, the concept of operation enables AUs to gain credit points in one hotspot and use them in another, meaning that even AUs with just one regulated flight in a hotspot can make use of the prioritisation mechanism. This supposes a great advance, since even the big airlines are also LVUCs in certain airports.

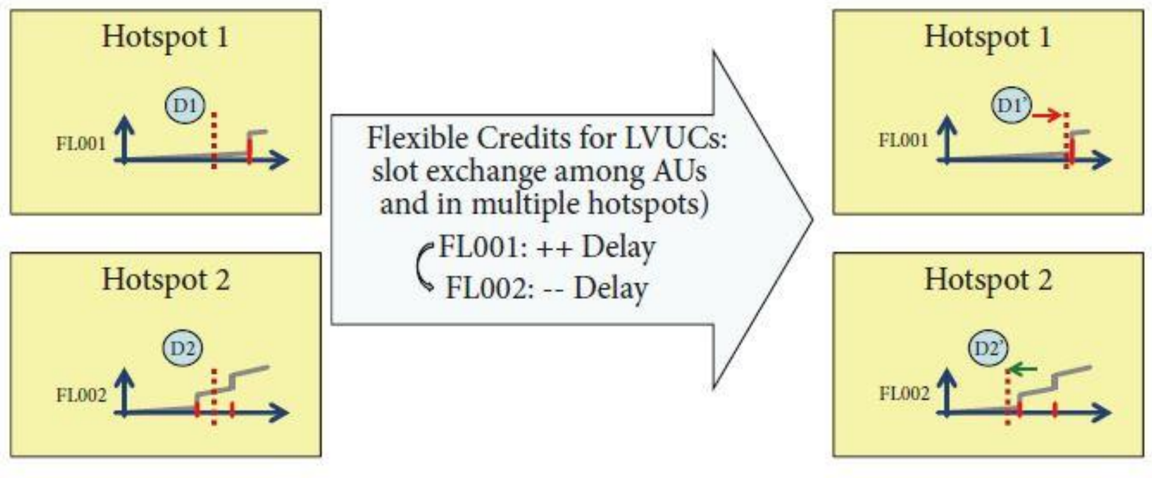

Figure 5. FCL mechanism with two hotspots

The operational concept underpinning ESFP is shown in Figure 5. The case of a LVUC airline having only one flight in two different hotspots is illustrated. With the mechanisms proposed by UDPP so far (ESS, SFP, FDR and Margins) the airline cannot make use of any prioritisation system in order to reduce the imposed delay and the associated cost of delay. The ESFP mechanism, however, enables the airline to sacrifice more delay in flight FL001 (Hotspot 1), whose operational margin is wider, without any high associated cost increase. In exchange for this delay absorption the airline receives an amount of credit points in accordance with the extent of delay accepted and can make use of this credit points to reduce the amount of delay imposed to its flight FL002 in Hotspot 2, which has a relevant influence in terms of cost.

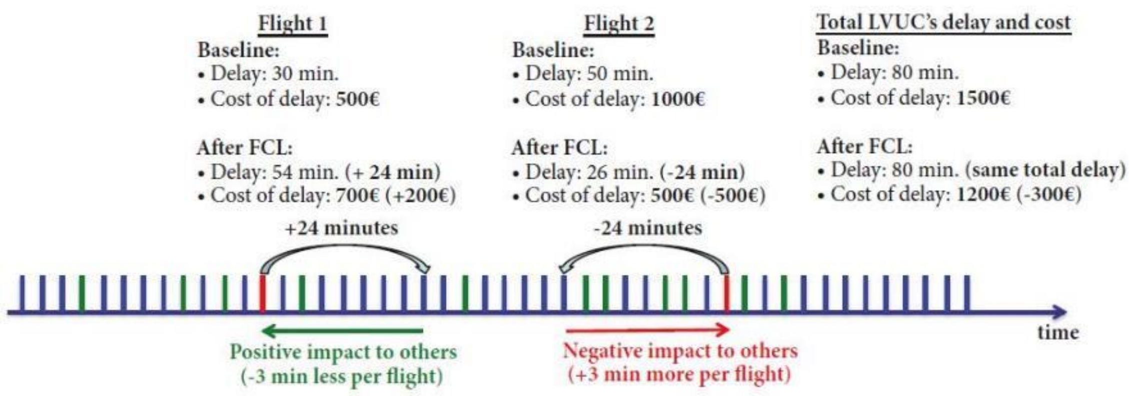

Figure 6. FCL mechanism with one hotspot

The ESFP mechanism is also suitable for use in one single hotspot, as illustrated in Figure 6. The timeline represents a sequence of ATFM flight slots belonging to different affected airlines. The airline represented by the red colour is a LVUC for the hotspot and can make use of the prioritisation mechanism. Accordingly, the airline decides to absorb some delay for Flight 1 (24 minutes) earning, in exchange, credit points (24 delay credits) which it uses downstream to reduce the delay imposed to its second regulated flight in the hotspot (Flight 2). As a consequence, due to the non-linearity nature of the cost of delay, the airline ends up reducing the total impact of delay (cost) by 300 Euros, while the total delay in the hotspot remains constant. The prioritisation carried out by the LVUC airlines have a negative impact on the originally scheduled flights between the baseline position and the new prioritized flight position upstream the timeline, typically approximately 2 or 3 minutes of flights' extra delay. However, according to AU experts consulted by EUROCONTROL during the development of the mechanism, such negative impact on other airlines can be considered negligible [12] -meaning acceptable if it remains below the "normal noise" in the network operations-.

The requirements of an AU to be classified as a LVUC may be different from one hotspot to another depending on the situation. Thus, even large airlines can often be considered as LVUCs in many hotspots (typically at airports in which they operate a few flights). The consideration of LVUC and the admittance to use the FCL mechanism to any AU which meets requirements can induce a higher level of acceptance to tolerate some degree of inequity in favour of LVUCs at some moment in time but with equity compensated over time [13].

3.3.3.2 Credit Points for Re-routing

Another concept making use of credits is proposed by Sheth and Gutierrez-Nolasco [14], which extends the credit-based paradigm to route prioritisation. Currently, AUs are only permitted to specify one route when delivering the Flight Plan. This route is set, as far as possible, according to their business model and following the AU utility function, however during times of reduced airspace or airport capacity AU preferences may change. The mechanism, Credit Points for Re-routing, relies on the ability of AUs to deliver optional routes for their flights, prioritising each one with credit points.

Prior to the start of each day, AUs receive a fixed number of credits based on the size of their operations. Then the AU is expected to privately assign a different amount of credits for each route option, as long as the maximum credit assignment for each flight is within the credit balance. When a sector is flagged as congested due to excess demand, the flight routes disclosed by the AUs are ranked by credits and the sector is filled up to capacity by the higher credit assignments. The flights whose routes are ranked with the lowest number of credits are assigned to their next route preference in the list and the whole simulation is repeated. The iterative method is run until there are no regions with excess demand. The mechanism needs the development of a centralised server in charge of processing the routes and computing potential regions of capacity imbalance. Thus, once the AUs assign credits for each route and flight, those points and routes are submitted to an automated server. Simulation results demonstrate that adding priorities to optional routes further improves system performance compared to filing one route per flight and using first-come first-served scheme [14].

3.4 Mechanisms summary

The following table summarizes the reviewed mechanisms.

Table 7. Summary of the mechanisms reviewed

Name	Deployed?	Inter-airline swaps?	Only for regulated flights?	Rule-based?	Centralised?	Market-based?	Takes airlines' cost into account?	Money-based?	Credit-based?
FPFS	Yes	No	Yes	Yes	Yes	No	No	No	No
ESS	Yes	Yes	Yes	Yes	No	No	Yes	No	No
DFlex	Yes (CDG)	No	Yes	Yes	Yes	No	Yes	No	No
FDR	No	No	Yes	Yes	Yes	No	Yes	No	No
SFP	No	No	Yes	Yes	Yes	No	Yes	No	No
FM	No	No	Yes	Yes	Yes	No	Yes	No	No
BPBS	No	No	Yes	Yes	Yes	No	No	Yes	No
Auction	No	Yes	Yes	No	Yes	Yes	Yes	Yes/No	Yes/No
CPLP	No	No	No	No	Yes	Yes	Yes	Yes	No
Route Contract	No	Yes	No	No	Primary Yes, Secondary No	Yes	Yes	Yes	No
FCL	No	Yes	Yes	No	Yes	Yes	Yes	No	Yes

3.5 BEACON flight prioritisation mechanisms proposed

Following the identification of flight prioritisation mechanisms, the project has selected some and combined them into 3 BEACON mechanisms that will be implemented. This selection followed several steps described below.

Firstly, all the mechanisms identified through the detailed literature review were analysed in a qualitative manner, in order to identify their theoretical advantages and shortcomings. Table 8 illustrates the main comments and potential deviations from rationality identified in the analysis.

Table 8. Flight prioritisation mechanisms analysis

Mechanism	Main comments	Potential deviations from rationality
ESS	• Operationally deployed • Possibility to include swaps between AUs	• Endowment effect[6] - low
DFlex	• Only for disruptions at the origin airport?	• Status quo - medium • Endowment effect - low
FDR	• Priorities defined in advanced (before hotspot is declared)	• Status quo - high • Other (e.g., familiarity)
SFP	• Very useful for situations where it is essential to bring a flight as close as possible to its original schedule • Priorities defined once the hotspot is declared	• Endowment effect - medium (only focussing on most valuable flight)
FM	• Translation of the cost function in time margin (time before, time after) • AUs may be reluctant to distribute this information	
FCL	• Provide flexibility to LVUCs • Extension to the SFP • Needs further definition, good for research exploration	• Hyperbolic discounting[7] - high • Endowment effect - medium

[6] Important aspect examined by prospect theory, which represents a cognitive bias to overvalue certain items already owned in relation to its objective (market) value.

[7] It refers to the tendency for people to increasingly choose a smaller-sooner reward over a larger-later reward as the delay occurs sooner rather than later in time.

BPBS	• Prioritisations are rewarded tactically but decisions are taken strategically (out of the scope)	• Over/Under optimism - medium • Hyperbolic discounting - high • Risk/Uncertainty aversion - medium • Status quo - medium
Auction	• Market mechanism: tends to optimize distribution of scarce resources	• Endowment effect - high • Hyperbolic discounting - high • Status quo - medium
CPLP	• Ineffective for regulations affecting airports capacity • Last-minute disruptions are not taken into consideration (unit rates are currently set once per year) • AUs take decisions at strategic level (out of scope)	• Endowment effect - high • Hyperbolic discounting - low
Route Contracts	• Prioritisations are rewarded tactically but decisions (type of contract) are taken strategically (out of scope)	

From this analysis, involving all consortium partners, the following initial mechanism selection was made.

Table 9. Initial pre-selection of BEACON flight prioritisation mechanisms

No.	Mechanism name
1	First Plan First Served (FPFS) → BASELINE
2	UDPP - Enhanced Slot Swapping (ESS) → BASELINE
3	UDPP - Fleet Delay Reordering (FDR)
4	UDPP - Selective Flight Protection (SFP)
5	UDPP - Flight Margins (FM)
6	UDPP - Flexible Credits for LVUCs (FCL)
7	Slot Auction, Slot Trading

From that initial pre-selection, an innovative method to include some of the identified mechanisms was proposed. The suggested concept consists of merging the selected mechanisms in a two-step approach comprising:

- **Sequencing of the flights** in the identified slots based on two possible principles:
    a) First Plan First Served (FPFS)
    b) UDPP Automation (FDR, SFP or FM)
- **Secondary 'market'** where the AUs can interexchange slots via slot swap, credits or money:
    a) UDPP - Flexible Credits for LVUCs (FCL)
    b) Slot Trading (Centralised\Decentralised)
    c) Secondary Auction

With this approximation, a series of compound mechanisms were derived and presented for discussion at the 1st Advisory Board (AB) meeting (11/11/2020). Table 10 illustrates this list.

Table 10. Potential combined mechanisms presented at the AB meeting

Mechanism label	Prioritisation principles included
A	1. UDPP Automation: UDPP – Flight Margins (FM) 2. Secondary 'market': Flexible Credits for LVUCs
B	1. UDPP Automation: UDPP – Flight Margins (FM) 2. Secondary 'market': Centralised Slot Trading
C	1. UDPP Automation: UDPP – Flight Margins (FM) 2. Secondary 'market': Decentralised Slot Trading (Secondary Auction)
D	1. Primary slot auction

The discussion focused on the advantages, limitations and possible barriers of implementation of each of the mechanisms from the perspective of the airlines, airports and ANSPs. The feedback received is summarized in the Table 11. Further details on this analysis, involving the Advisory Board, can be found in deliverable D6.1.

Table 11. AB feedback on the mechanisms

Mechanism	Advantages	Limitations	Barriers to implementation
Flight Margins (FM) + Flexible Credits for LVUCs (FCL)	Margins information can easily be shared with the central point and can ensure good flexibility as they are directly linked to operations. This could be flexible enough even for small airlines. Airlines can absorb some delay in exchange for credits to	There is a question of the initial endowment of credits, and the time cycle in which they can be used, and when they expire. Further issue is linked with the geographical scope of the credit There is also the question of how to manage the changes in the schedule and its	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 re. security of priority / cost data

	be used to protect an important flight.	impact on airport capacity	being accessed/ inferred by others
Flight Margins (FM) + Centralised Slot trading	The NM has a system overview as all requests are collected and evaluated by them, as the 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); lower workload when compared to de-centralised approach	This mechanism might induce additional 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 for airlines. Equity needs to be introduced.	The costs of supporting this process are not negligible. Also here concerns regarding security of data being shared. Some airlines might not have enough people to participate in the decision process.
Flight Margins (FM) + Decentralised Slot trading	Flexible, and no need to communicate preferences. Could be quicker to implement as it would be implemented on a commercial, not political side.	High workload for airlines, which has to be minimized 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.	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	The process is simple and fairly transparent, and it gives complete flexibility to airlines.	It is likely that big airlines will be advantaged as they have more resources to commit to auctions. Strong opposition from airlines to use money.	A big investment in a software to automatise the process would be needed to ensure equity. 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.

Following these comments from the Advisory Board, the selection of proposed mechanisms was re-evaluated. The mechanism based on the decentralized approach is not chosen for implementation within the BEACON models. Two reasons must be highlighted for that decision: (i) the considerable workload that it would entail for the airlines in real operations; (ii) the lack of information that the airlines have on the interests of other airlines would drastically worsen the acceptance of swaps and therefore the effectiveness of the mechanism.

At the same time, the same Advisory Board's feedback served to make different adjustments in the mechanisms that will finally be implemented in BEACON, which are: Flight Margins (FM) + Flexible Credits for LVUCs (FCL), Flight Margins (FM) + Centralised Slot trading and Primary Auction. The formal definition and operation of these mechanisms, which is exposed below, is currently lacking of some series of implementation details at a very low level that will be tackled during the implementation phase (WP4 and WP5) to avoid excessive rigidity in the mechanisms' descriptions, which could make difficult its future implementation.

3.5.1 Flight Margins (FM) + Flexible Credits for LVUCs (FCL)

This mechanism relies on the operation of two different concepts, the flight margins and the flexible credits. The specific application of these two concepts can take different approaches. In this regard two different procedures have been proposed. The first one is closely aligned with the work on flexible credits performed by the UDPP team within EUROCONTROL. The second one suggests an innovative method where airlines are able to buy and sell priorities for all their flights of the day through the use of credits.

The latter approximation still lacks a formal definition and requires further discussion in order to identify the suitability and feasibility of its implementation. On the other hand, the first suggested approach, based on the UDPP research, is illustrated in the Figure 7 and consists of the following steps:

- When the Network Manager detects a demand-capacity imbalance, it activates a regulation and orders the affected flights according to the operational margins provided by the airlines in advanced. This process can be subdivided in two stages:
    1. The Network Manager sequences the flights according to the FPFS principle.
    2. Given the first FPFS sequence and the operational margins of the flights, the Network Manager reorders the flights of each airline in the slots previously assigned by the FPFS principle.
- Once the slot sequence is produced, each airline receives their corresponding ATFM slots for their affected flights. Here, the airline evaluates the associated cost of delay associated with each one of the received slots and makes three possible decisions:
    a) Stay the same. Accept the ATFM slots received for all the flights.

   b) Absorb greater delay. This implies the change request of one flight to a later ATFM slot in the hotspot. In return, the airline will receive a compensation in the form of credits.

   c) Prioritise a flight. This implies the change request of one flight to an ATFM slot located in an earlier position in the hotspot. As payment to advance the flight, the airline will have to pay a series of credits.

- The airlines send their final requests back to the Network Manager for it to accept them or reject them according to some defined requirements, for instance the schedule restrictions. Finally, the Network Manager matches the accepted offers and produces the final schedule.

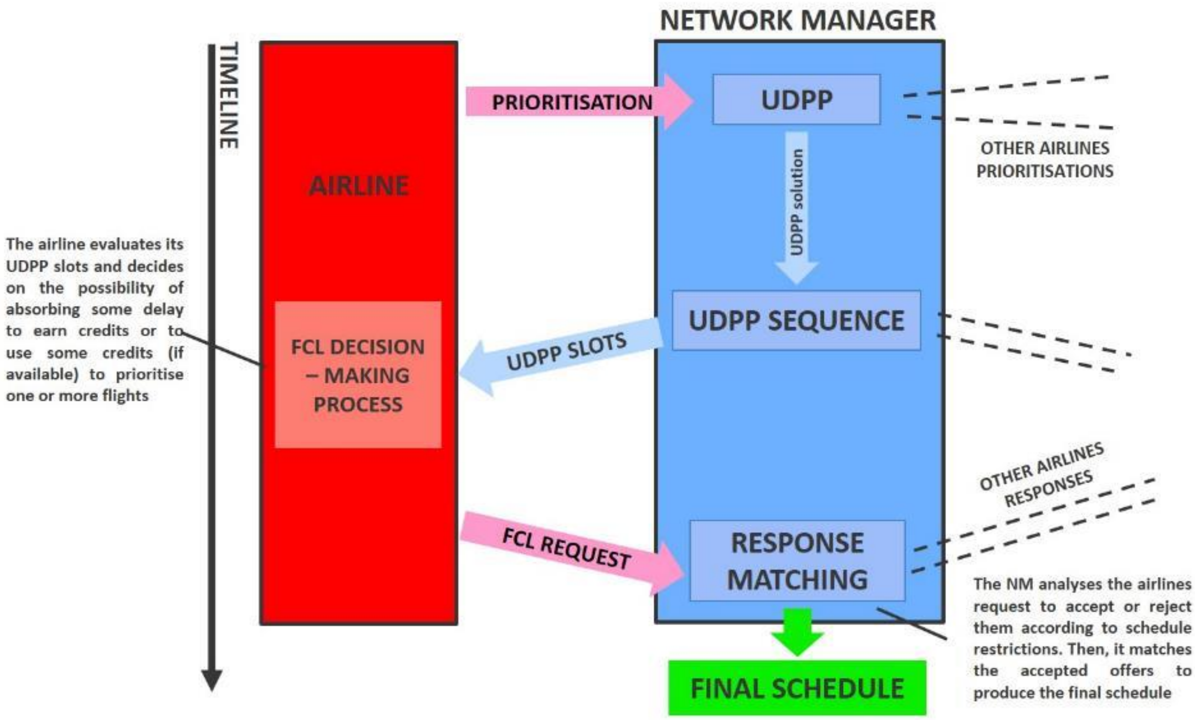

Figure 7. Workflow for the mechanism on Flight Margins (FM) + Flexible Credits for LVUCs (FCL)

This approach requires the definition of a series of assumptions regarding the notion of the flexible credits and the slot assignments. Some are listed below, however, note that these assumptions are still open to discussion and may be subject to slight changes during the implementation phase of the mechanism.

- The equivalence between delay and credit, required to compute the amount of credits in use to prioritise a flight or to absorb some delay, will be initially set to a 1:1 relation, meaning that one-minute of delay equals one-credit. This approximation can be fine-tuned during the implementation phase of the mechanism.

- The credits that are earned can be used in the future without any type of expiration deadline. This assumption, however, is notably conditioned by the temporal scope of scenarios chosen and could change if, for example, it is decided to simulate two different seasons (winter and summer).

- All the airlines affected in the hotspot can use the credit-based mechanisms regardless of the number of flights affected within the hotspot.

- When more than one airline is interested in same ATFM slot in the sequence a specific slot assignment procedure needs to be followed. Two different approaches have been identified:
  - Temporal criteria: *'first come first served'* approach. We can simulate it by applying a random order in the airlines requests and simulate the same scenario n times.
  - Value criteria: credit-based auction of the slots in conflict. This would alter the price of the credit: more credits to decrease the same value of delay that was absorbed in the action that won them.
- The credits earned in a sector by an airline can be used in another sector, the geographical scope of use of the credits is global. Unit rates may be included to take into account the different levels of congestion between sectors but this is something that needs to be further discussed.

3.5.2 Flight Margins (FM) + Centralised Slot trading

This mechanism is also based on the union of two different and complementary concepts: UDPP mechanism, and a process of creating swap offers by the Network Manager based on the prioritisation given by the UDPP.

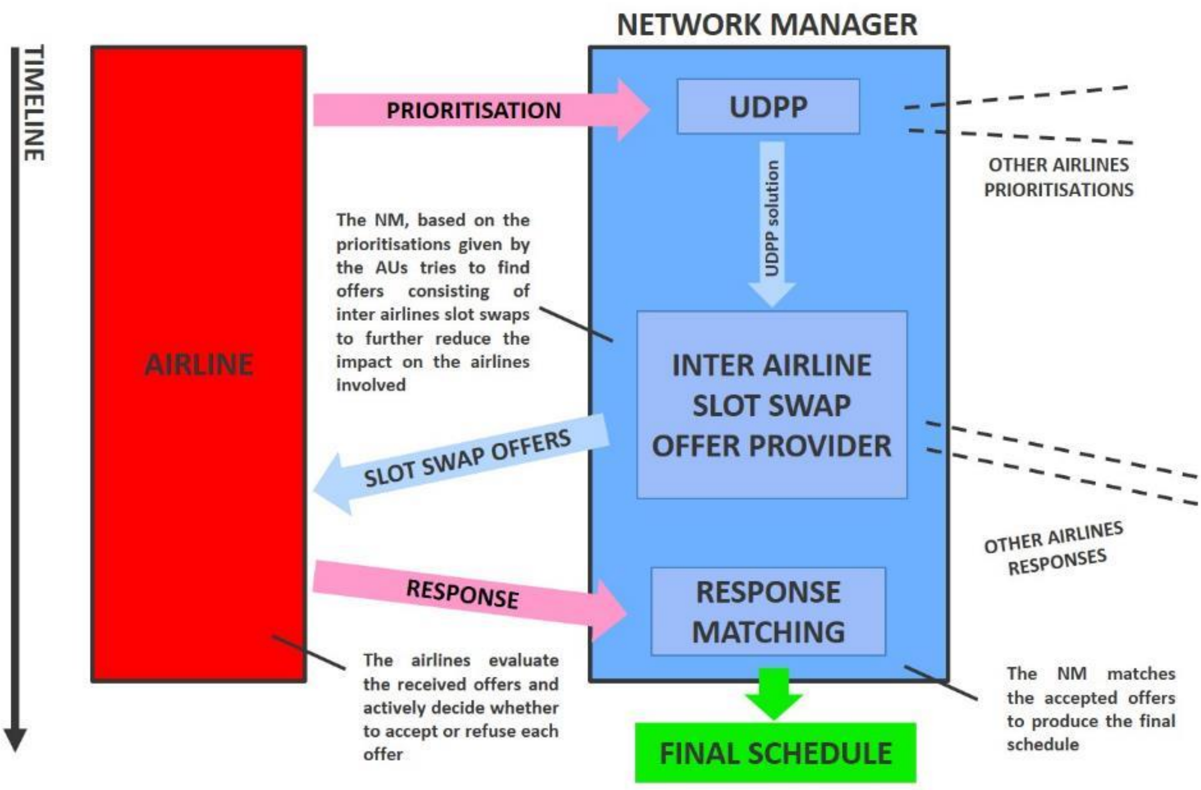

Figure 8. Workflow for the mechanism on Flight Margins (FM) + Centralised Slot trading

The suggested operation of the mechanism is illustrated in Figure 8 and consists of the following steps:

- When the Network Manager detects a demand-capacity imbalance, it activates a regulation and orders the affected flights according to the operational margins provided by the airlines in advanced. This process can be subdivided in two stages:

1. The Network Manager sequences the flights according to the FPFS principle.
2. Given the first FPFS sequence and the operational margins of the flights, the Network Manager reorders the flights according to the UDPP mechanism.

- Once the slot sequence is produced, the Network Manager, based on the prioritisations given by AUs (margins and priorities) tries to find offers consisting of inter airline swaps to further reduce the impact on the airlines involved.
- The airlines evaluate the received offers and decide whether to accept or refuse each offer. The swap offer will only be considered accepted if all airlines involved in the swap agree.
- Finally, the Network Manager matches the accepted offers to produce the final schedule.

3.5.3 Primary Auction

Unlike the previous mechanisms, the auction-based concept does not start from a first UDPP ordering of the ATFM slots, but it provides a scenario where the sequence is the result of the amount of money airlines are willing to pay to occupy each of the auctioned slots. However, due to the strong opposition from airlines to pay for the ATFM slots, it was necessary to introduce some other type of virtual currency to replace the use of real money.

The proposed auction-based mechanism uses a primary auction and a series of priority points as an artificial currency. These priority points are distributed to all airlines at the beginning of the simulation as an initial allocation based on the size of their operations (e.g., km flown). The amount of priority points in play will remain constant throughout the simulation. Consequently, once distributed, these points are not created or destroyed, they will only move from one airline to another as a result of the different auctions.

Every time the network manager detects a demand-capacity imbalance, it will activate a regulation and calculate the different ATFM slots. Then, these ATFM slots will be auctioned following a set of rules and simulation assumptions:

- Airlines will place their bids according to the cost of delay of each flight and the value they assign to the priority points in terms of cost of delay (e.g., 1 priority point = 1 EUR cost of delay). Learning capabilities can be introduced, allowing the airline to change its monetary value of the priority point depending on previous events.
- All the ATFM slots are auctioned at the same time. Airlines decide their bids for all the ATFM slots included in the hotspot following the restrictions imposed by their scheduled departure time.
- The bids can be negative (negative priority points e.g., -15), meaning that the airline will receive priority points if ends up with that slot. These negative bids will be concentrated on the slot positions that imply a high cost of delay for the airlines, as a compensation, if they win the slot, they will be rewarded with the amount of priority points bid.
- The airline sends different bids for each one of the available ATFM slots for each affected flight. For a particular flight, the sum of all ATFM slot bids of the airline inside the hotspot has to be equal to zero and the maximum bid cannot be higher than the number of priority points owned by the airline in that moment.

- Following the assumption by which the number of credits in the system must remain constant, when a hotspot auction ends, the excess priority points (equal to the sum of all bids, both positive and negative) are distributed proportionally among all airlines. As a result, the winning airlines with positive bids will pay slightly less points, while the winning airlines with negative bids will receive a slightly higher number of points.

To avoid overhead for airlines, this mechanism could be automated into a client-system in each airline, that would submit the bets when it is requested from the NM. Each airline's client-systems would know the cost of delay and value of credits specific to the airline, that would need to be calibrated for each airline.

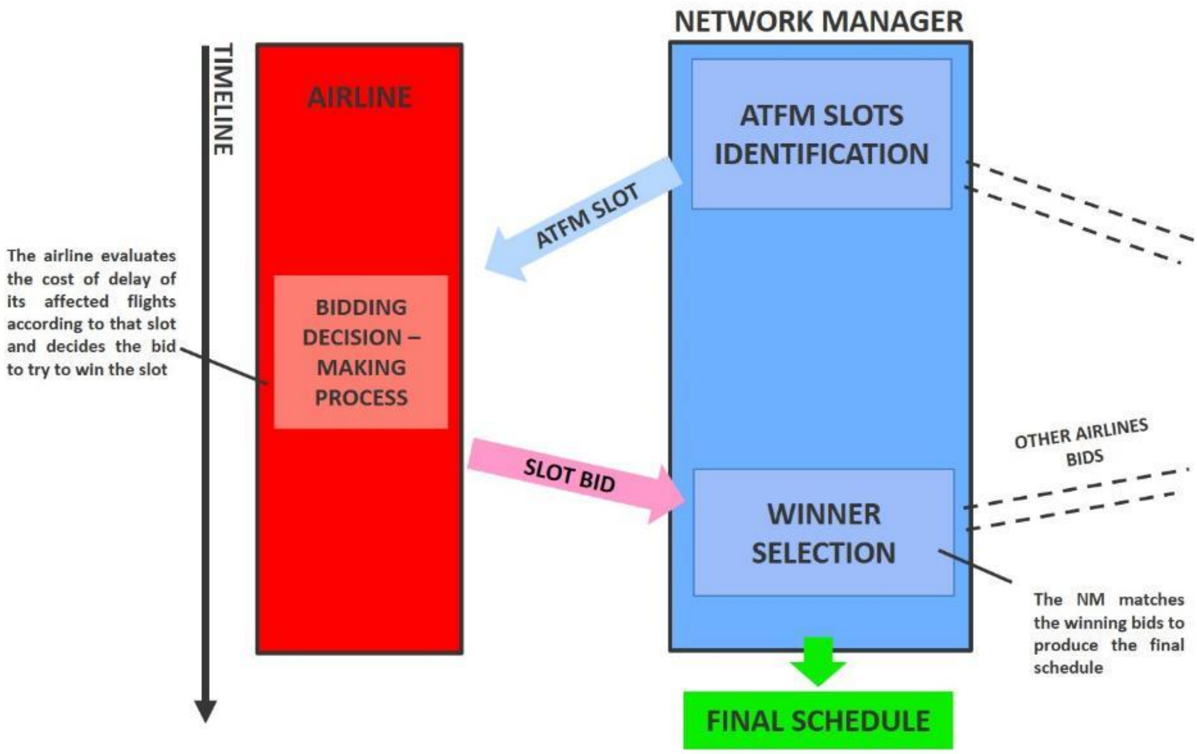

Figure 9. Workflow for the mechanism based on a primary auction

4 Scenarios definition

In order to test the different mechanisms, BEACON defines a set of scenarios that will simulate typical situations in which the mechanisms can be used by the airspace users.

The concept of "scenario" may differ from project to project. In BEACON, a scenario is considered as a *set of values for input variables to model*. While this definition is exact from the implementation point of view, it is useful for the project to reflect on the different types of inputs of the model as they also structure the model. In BEACON, we believe that the input variables can be structured in four categories:

- The traffic setup. This category includes all the specific schedules, flights, passengers etc. included in the simulations. They form the backbone of any scenario.
- The traffic conditions. This category gathers all variables that are linked to the conditions in which the traffic is realised, for instance delay levels.
- The active mechanisms. These variables simply indicate the presence of the mechanisms that the project wants to test.
- The active biases. The variables include the behavioural parameters for different agents, particularly the ones driving non-rational behaviours in these agents.

In the following, we explain the high-level choices made by the project regarding each of these categories. Because we have several possibilities for each, and because we cannot test every combination due to their numbers, we present in section 4.5 a prioritisation for scenarios.

Because we have two distinct models (produced in WP4 and WP5 respectively), we need to define scenarios for both. In the following, we use "model A" for the scenarios produced in WP4 and "model B" for the scenarios produced in WP5. We also highlight the differences between these scenarios when relevant. As a reminder, model A and model B are different in scope:

- Model A will be small scale, focused on a few airports and a small portion of the airspace. It will feature advanced capabilities in terms of mechanisms, but without taking the full complexity of the European airspace. It is meant to produce some insight, using toy example and synthetic data.
- Model B has a larger scale, spanning the entire European airspace. It will use more empirical data, more realistic setups and so on. This second model is meant to compute KPIs with a high degree of fidelity, taking into account full network effects.

4.1 Traffic setup

The traffic setup gathers all variables that are linked to the choice of the flights, passengers, airspace, airports, etc.

For them we considered several possibilities. One of them was to use some setup similar to what has been done in the past during the UDPP core project, based on their deliverable. This solution has been discarded, due to the difficulty to reproduce the exact conditions, partly due to the lack of details in the deliverables, and partly due to the impossibility to get the data required for that (for instance the date used for some exercises is 15/07/2016, a day for which traffic data is unavailable to us due to the closure of DDR2[8] data for research purposes).

We also had to consider how much we use historical data as opposed to synthetic data, which may be easier to setup and control. By synthetic data we mean for instance made-up schedules for flights, which may be loosely based on historical data for realism but modified to study a particular aspect of the model. Synthetic data will likely be used for model A, as explained below, whereas model B will use historical data.

4.1.1 Temporal scope

Because of the level of detail required, the project found relevant to consider a temporal scope up to a single day of operation. In other words, the input data for the traffic setup will include schedules, passenger itineraries etc., happening in one day.

Note that this decision does not prevent us to study long-term decisions from airspace users, because one day can be repeated through an iterated simulation. Note also that our models are stochastic, so two repetitions of the same ‘day’ would not be exactly the same. Iterating ‘games’ typically allow the agents to build up realistic expectations, allowing to make long-term decisions by estimating their long-term return. Alternatively, expectations from agents may be adjusted by other means.

From a data point of view, we will use historical data from one day of operation in September 2018, as explained in D2.1. We are using only one day, which is dictated by the effort and budget (i.e., obtaining passenger and schedule data) needed to prepare the data of that one day for the models. As a consequence, the project will always highlight that the results have been obtained on a single day, which hopefully is sufficiently typical to capture relevant effects (see D2.1 for the choice of the test day).

The day in question has been very carefully chosen and curated to represent a ‘typical’ busy day on 2018. Of course, we acknowledge the fact that it cannot represent perfectly any day in the year. Therefore, we are conscious that the results obtained are valid conditionally. However, it is also important to remember that delays, wind, taxi-times etc are sampled from a much bigger dataset that just this one day (typically months of data). Therefore, several runs of the stochastic simulator give quite different results, which represent notionally different 'realisations' of the same operations (defined here in terms of schedules and itineraries). Hence, we are confident that the results are fairly generalisable and typical of the day-to-day operations.

4.1.2 Traffic setup for model A

For model A, we plan to use a single traffic setup. This setup includes a small number of airports (most probably 5), comprising at least one hub and one regional airport. All flights between these airports will be considered, and airport capacities will be adjusted. Passenger connections among these airports will be considered. Finally, a synthetic airspace will be designed around these airports, to be able to study airspace regulations and airspace-related network effects.

[8] Demand Data Repository.

Overall, the data for model A will partly come from historical data but will be modified to study a simplified situation, to better understand the mechanisms and biases in a simple framework.

In the following, the traffic setup for model A is simply referred as "A" in our nomenclature.

4.1.3 Traffic setup for model B

With model B, we can use two different traffic setups. One of them (called "B1") will mirror the traffic setup used for model A. This will allow us to cross-check the behaviour of this model with model A.

More interestingly, setup B2 will consider a full European scenario where all flights (around 30 000) and all airports (around 800) in one day of operations are considered. More specifically, all flights departing to and from an airport in Europe in the time frame will be considered.

4.2 Traffic conditions

The traffic conditions gather variables that are not included in the traffic setup but have a direct impact on it. Given the level of details we have in the models, we expect to include in this category at least:

- ATFM regulations,
- non-ATFM delay distributions,
- taxi times, turnaround times, etc.,
- passenger connecting times,
- exogenous cancellation rate.

Among these variables, we chose to fix all of them except for regulations. Distributions will be generated through historical analysis of data.

4.2.1 Traffic conditions for Model A

In order to keep things simple for this model we will define (artificially, based on the historical data review) three regulations and compute their impact on the overall system:

- R1: regulation at a big hub.
- R2: regulation at a regional airport.
- R3: regulation in a central airspace.

The regulation details (length, severity) will be decided at a later stage, but the regulations should have a sufficient impact to allow agents (i.e., stakeholders) to have a significant reaction. We also define R4, the combination of R1, R2, and R3, happening at the same time.

4.2.2 Traffic conditions for Model B

First, traffic conditions R1, R2, R3, and R4 could be directly used in model B1, as it mirrors the traffic setup A.

However, they cannot be used directly in the second setup B2, given that B1 and A are partly setup using synthetic data. However, we can use similar traffic regulations, using for instance:

- R1': regulation at Charles-De-Gaulle.
- R2': regulation at Birmingham.
- R3': regulation somewhere in MUAC.
- R4': combination of R1', R2', and R3'.

The situation at these airports and airspace may be sufficiently close to the ones in the synthetic data to ensure some reliable comparisons.

Finally, the model can use traffic conditions "R5", in which regulations are stochastically created, based on historical data. In this case, regulations from historical data are sampled and applied on the model during simulation. Regulations can be filtered by severity to allow different levels of stress in the system. This allows to study the impact of mechanisms in a more realistic setup and draw conclusions about the impact on the entire system.

4.3 Active mechanisms

The third layer in the scenario architecture scenario is the mechanism(s) that will be available to the airspace users. These mechanisms are described in more detail in section 3. They are summarised in Table 12.

Table 12. List of mechanisms possible

Code	Mechanisms summary
-	Baseline: First Plan First Served (FPFS) + Enhanced Slot Swapping (ESS)
M1	Flight Margins (FM) + Centralised Slot trading
M2	Flight Margins (FM) + Flexible Credits for LVUCs (FCL)
M3	Primary auction

A possible additional variable that could be considered is the take-up, i.e. the proportion airports/AUs that use the mechanisms. In order to keep the total number of scenarios manageable, we decided not to include this variable. In other words, mechanisms will be available at every regulation for every airline.

4.4 Active biases

Finally, the last layer of the scenario is the human biases within the agents that BEACON will introduce in the simulation in order to study and compare their impact on the performance of the prioritisation mechanisms. This is one of the main objectives of BEACON. Indeed, in the baseline, agents will behave fully rationally, but we would like to test the introduction of some biases in the system and analyse their impact. Indeed, behavioural biases are an important part of the human decision process. For more details about these biases, one can refer to D6.1, in particular section 2.

These behaviours will be embedded in the decision process of the agents by modifying some behavioural parameters. For instance, when an agent computes that a decision will allow them to gain X credits, they will have an expectation on how much these credits can save them in terms of cost in the future. If the reward is expected to be in X days and hyperbolic discounting is active, then the expected reward will be discounted accordingly. Likewise, if some risk-aversion is active, future cost savings utility will be reduced to reflect the statistical unlikelihood of a risky decision (using a convex function), the output of which will be used to compare potential decisions.

Table 13. List of biases

Bias code	Name and short description	Note
-	Baseline, agents take best (computable) solution based on their (incomplete) information and expectations	
HD	Hyperbolic discounting: agents discount future reward.	Independent from RA and PT
RA	Risk aversion: agents have a convex utility function, having aversion to high risks.	
PT	Prospect theory: agents exhibit loss aversion and use a reference point.	Includes RA

Based on the questionnaires prepared as part of WP4, we may slightly modify this list depending on the behaviours revealed in the responses to the survey.

Note that the hyperbolic discounting mechanism can be applied independently of the others, and that prospect theory can include some risk aversion. So, the possible combinations are the following:

- HD
- RA
- PT
- HD + RA
- HD + PT

4.5 List of scenarios

In total, we can combine traffic setup, traffic conditions, active mechanisms, and active biases. As always in these cases, combinatorial complexity dictates making choices on scenarios to implement. To guide our choice, we present our priorities in Table 14 (for model A) and Table 15 (for model B).

We use four levels of priorities:

- Priority 1: we will simulate these scenarios no matter what. They form the core of the project and are needed to reach the objectives.
- Priority 2: these scenarios are highly desirable. They have a clear interest for the project, but we do not risk to miss some objectives if we do not have the time to simulate them.

- Priority 3: these scenarios are interesting from a scientific point of view, as a complement to the others. They may be simulated for exhaustivity and/or more focused studies, i.e. for a scientific publication.
- Priority 4: We do not plan to simulate these scenarios within BEACON.

We do not show all possible combinations in the tables. Instead, we show only combinations for R1 and R4 in Table 14 for model A. Combinations for R2 and R3 are the same and have the same priorities than R1. Moreover, any other combination is considered of lower priority (4).

Table 14. Scenario prioritisation for model A

Traffic setup	Traffic conditions	Active mechanisms	Active biases	Nomenclature	Comment	Priority (low numbers are highest priority)
A	R1	-	-	A.R1	Baseline	1
		M1		A.R1.M1	Rational baseline for M1	1
		M2		A.R1.M2	Rational baseline for M2	1
		M3		A.R1.M3	Rational baseline for M3	1
		M1	HD	A.R1.M1.HD		1
		M2		A.R1.M2.HD		1
		M3		A.R1.M3.HD		1
		M1	RA	A.R1.M1.RA		2
		M2		A.R1.M2.RA		2
		M3		A.R1.M3.RA		2
		M1	PT	A.R1.M1.PT		1
		M2		A.R1.M2.PT		1
		M3		A.R1.M3.PT		1
		M1	HD+PT	A.R1.M1.HD+PT		3
		M2		A.R1.M1.HD+PT		3
		M2		A.R1.M1.HD+PT		3
	R4	-	-	A.R4		2
		M1		A.R4.M1		2

		M2		A.R4.M2		2
		M3		A.R4.M3		2
		M1	HD	A.R4.M1.HD		2
		M2		A.R4.M2.HD		2
		M3		A.R4.M3.HD		2
		M1	RA	A.R4.M1.RA		3
		M2		A.R4.M2.RA		3
		M3		A.R4.M3.RA		3
		M1	PT	A.R4.M1.PT		2
		M2		A.R4.M2.PT		2
		M3		A.R4.M3.PT		2
		M1	HD+PT	A.R4.M1.HD+PT		3
		M2		A.R4.M1.HD+PT		3
		M2		A.R4.M1.HD+PT		3

For model B, overall, we consider that setting up the traffic B1 (same as A) is of lesser priority. If we do it, it will be mainly for cross-validation purposes, so we set this to priority 3. Instead, we focus here on the larger model, B2, and especially on the use of stochastic regulations (R5), for which we are interested in simulating all mechanisms, with and without behavioural biases. All combinations not appearing in the table are considered of lower priorities (4).

Table 15. Scenario prioritisation for model B

Traffic setup	Traffic conditions	Active mechanism	Active bias	Nomenclature	Comment	Priority (low numbers are highest priority)
B2	R5	-	-	B2.R5	Full European-wide baseline	1
		M1		B2.R5.M1	Full European-wide rational baseline for M1	1
		M2		B2.R5.M2	Full European-wide rational baseline for M2	1

		M3		B2.R5.M3	Full European-wide rational baseline for M3	1
		-	HD+PT	B2.R5.HD+PT		1
		M1		B2.R5.M1.HD+PT	Full scenario for M1 with BE.	1
		M2		B2.R5.M2.HD+PT	Full scenario for M2 with BE.	1
		M3		B2.R5.M2.HD+PT	Full scenario for M3 with BE.	1
		-	HD	B2.R5.M1.HD		2
		M1		B2.R5.M1.HD		2
		M2		B2.R5.M1.HD		2
		M3		B2.R5.M1.HD		2

5 References and Acronyms

Applicable documents:

[1] Grant Agreement No 893100 BEACON – Annex 1 Description of the Action.
[2] BEACON Consortium Agreement
[3] Beacon D1.1 Project Management Plan, Issue 1, July 2020

Reference documents:

[4] PJ19.04 D4.4 SESAR Performance Framework (2018) 01 00 00
[5] D1.4 CFT 16-220862-A, Concept Document for Absolute Priority – Contributions to the OSED PJ07S01
[6] EUROCONTROL (2020), ATFCM USERS MANUAL, https://www.eurocontrol.int/sites/default/files/2020-05/eurocontrol-atfcm-user-manual-22052020.pdf
[7] Cook, A.J. and G. Tanner (2015) "European airline delay cost reference values", EUROCONTROL Performance Review Unit.
[8] N. Pilon, S. Ruiz, A. Bujor, A. Cook and L. Castelli (2016) "Improved flexibility and equity for airspace users during demand-capacity imbalance – an introduction to the user-driven prioritisation process", in Schaefer D. (Ed.), Proceedings of the 6th SESAR Innovation Days, Delft, Netherlands.
[9] NextGen JPDO (2011) "Flight Prioritisation Deep Dive: Final Report".
[10] L. Castelli, R. Pesenti, and A. Ranieri (2011) "The design of a market mechanism to allocate Air Traffic Flow Management slots", Transportation Research Part C: Emerging Technologies, Vol. 19, Iss. 5, pp. 931-943.
[11] T. Bolić, L. Castelli and D. Rigonat (2017) "Peak-load pricing for the European Air Traffic Management system using modulation of en-route charges", European Journal of Transport and Infrastructure Research, 17(1), pp. 136-152.
[12] R. Jovanović, N. Ivanov, G. Pavlović, O. Babić, F. Fichert, A. Strauss and S. Starita (2018) "Coordinated capacity and demand management in the European Core Area: results of a large-scale COCTA case study", in Schaefer D. (Ed.), Proceedings of the 8th SESAR Innovation Days, Salzburg, Austria.
[13] S. Ruiz, L. Guichard and N. Pilon and K. Delacourte (2017) "A New Air Traffic Flow Management User-Driven Prioritisation Process for Low Volume Operator in Constraint: Simulations and Results", Journal of Advanced Transportation, vol. 2019, Article ID 1208279
[14] Sheth, K. S., Gutierrez-Nolasco, S. (2010) "Analysis of factors for incorporating user preferences in air traffic management: a system perspective", 27th Congress of the International Council of the Aeronautical Sciences (ICAS).

Acronym	Meaning
AB	Advisory Board
AOBT	Actual Off-Block time
ATFM	Air Traffic Flow and Capacity Management
ATFCM	Air Traffic Flow and Capacity Management
ANS	Air Navigation Service
ANSP	Air Navigation Service Providers
AU	Airspace User
BPBS	Best Performing Best Served
CTOT	Calculated Take-Off Time
CPLP	Central Peak-Load Pricing
CDM	Collaborative Decision Making
A-CDM	Collaborative Decision-making Airport
CP	Central Planner
DC	Delay Credit
DFlex	UDPP Flexible Departure
EOBT	Estimated Off-Block Time
ESS	Enhanced Slot Swapping
ESFP	Enhanced Selective Flight Protection
ETO	Estimated Time Over
FCL	Flexible Credits for Low Volume Users in Constraint
FM	Flight Margins
FPFS	First Planned First Served
FPL	Flight Plan
FDR	Fleet Delay Reordering
HD	Hyperbolic Discounting
ICAO	International Civil Aviation Organisation
HP	Human Performance
KPA	Key Performance Area
KPI	Key Performance Indicator
LAQ	Local Air Quality
LVUC	Low Volume Users in Constraint
NM	Network Manager
PDS	Predeparture Sequence
PBO	Performance Based Operations
PT	Prospect Theory
RA	Risk Aversion
RBE	Ration by Effort
SESAR	Single European Sky ATM Research
SES	Single European Sky
SFP	Selective Flight Protection
SOBT	Scheduled Off-Block Time
UDPP	User Driven Prioritisation Process
TSAT	Target Start-up Time
TTOT	Target Take-Off Time