Working Paper 4

ACCESS Simulation Framework Specification

November 2015

Authors

University of Valladolid

Mario Ramírez

Félix Villafáñez

Alberto Araúzo

Adolfo López

Cesáreo Hernández

Nommon Solutions and Technologies

Ricardo Herranz

Ignacio Rodríguez

Antonio Martín

Advanced Logistics Group, Indra-Europraxis

Andrea Ranieri

Núria Alsina

Università degli Studi di Trieste

Lorenzo Castelli

Tatjana Bolic

This work is co-financed by EUROCONTROL acting on behalf of the SESAR Joint Undertaking (the SJU) and the European Union as part of Work Package E in the SESAR Programme. Opinions expressed in this work reflect the authors' views only and EUROCONTROL and/or the SJU shall not be considered liable for them or for any use that may be made of the information contained herein.

Table of contents

Executive summary

ACCESS will develop a simulation platform whose aim is to allow the evaluation of several alternative airport slot allocation mechanisms along different scenarios. Within this general aim, this toolset has several particular objectives:

- Allow the scientific study and analysis of different slot allocation mechanisms (administrative, optimisation-based, market-based and hybrid mechanisms), their parameters and possible configurations.
- Support the interaction between realistic models of the main stakeholders (airlines, airports, slot allocation coordinator and passengers).
- The representation of different realistic scenarios corresponding to real world situations characterised by sets of exogenous factors that may have significant impact on airport slot allocation and therefore on the mechanisms supporting this process.
- Provide regulators and policy makers with a tool that facilitates the understanding of how different allocation mechanisms perform according to relevant Key Performance Indicators.
- Provide a database that can be used for further studies.

The present document contains the technical specification of the ACCESS simulation environment, including:

- Functional requirements (including theoretical models and algorithms).
- Non-functional requirements.
- System architecture (software and hardware requirements).

1. Introduction

1.1 Scope and objectives

The general purpose of this document is to define the requirements for the development of the ACCESS simulation environment.

The document is expected to comply with a number of lower level objectives:

1. Define functional requirements (including theoretical models and algorithms).
2. Define non-functional requirements.
3. Define system architecture requirements (software and hardware).

1.2 Structure of the document

The document is structured as follows:

- Section 1 defines the main concepts and terms used throughout the document.
- Section 2 presents an overall view of the ACCESS simulation platform.
- Section 3 describes a set of requirements to be satisfied by the simulation platform.

1.3 Glossary of terms

Concept or term	Definition
Active Agent	A particular agent set with capability to initiate an interaction with other agents pursuing a certain goal, therefore influencing them. (See also *Agent* and *Passive Agent*).
Actor	See *Stakeholder.*
Administrative Slot Allocation	Slot allocation mechanism based on administrative rules, not including market or other types of mechanisms. The current slot allocation process, based on the EU regulation and IATA slot guidelines, is a particular case of administrative slot assignment.
Agent	An autonomous discrete entity with its own goals and behaviour, generally used to represent a certain stakeholder in a model. Autonomy means that it is capable to adapt and modify its own behaviour, which is guided by an objective function and a set of decision rules or algorithms of different complexity.
Agent-Based Model	A class of computational model for simulating the actions and interactions of autonomous agents (both individual and collective entities such as organisations or groups) with a view to assessing their effects on the system as a whole. It consists of: a set of agents, a set of agent relationships, and a framework for simulating their behaviours and interactions.
Agent-Based Modelling and Simulation	A class of computational simulation to run Agent-Based Models. It is based on local interaction among agents, and no central authority exists to operate the system or control its evolution or change of state.
Auction Market	A market where products, services or rights are bought and sold through a formal

Concept or term	Definition
	bidding process.
Combinatorial Auction	An auction where participants can place bids on combinations of discrete items, or "packages", rather than individual items or continuous quantities.
Congestion Pricing	Capacity demand management mechanism consisting in surcharging users for the use of scarce capacity to regulate demand, by establishing different prices along the day based on marginal congestion costs.
Coordination Interval (or Coordination Time Interval)	Period of time comprising the valid time for a slot to be used at certain airport. It is given different names across literature, such as 'coordination interval', 'time interval' or 'slot width'. Several slots may be allocated within the same coordination interval. The coordination interval has different duration at each airport (constant along the whole day), usually between 5 and 20 minutes (and up to 60 minutes in some cases).
Coordination Parameters	This set encompasses capacity, connecting times, night curfews, etc. They are specified for each airport before the season starts.
Endogenous Variable	Variables whose value is determined by the functional relationships in a model. They vary as a result of the execution of the simulation. (See also *Variable* and *Exogenous Variable*)
Event	A situation during simulation where some action is triggered. Examples are: a communication attempt, an attribute change, a decision process, etc.
Exogenous Variable	Variables that affect a model without being affected by it. They are used for setting arbitrary external conditions. Useful models require strict delineation regarding what is included and excluded from the model, as typically not all relevant subsystems can be represented. We therefore define parts of the system that are unaffected by other parts within the system. These components, which are relevant but unaffected by the model, are taken into account as exogenous variables. (See also *Variable* and *Endogenous Variable*)
Experiment	A set of scenarios representing several interrelated case studies (e.g., simulation of a certain slot allocation mechanism for a variety of scenarios).
Forward Market	An over-the-counter market where the items traded are usually contracts for specific quantities at a specified price with delivery set at a specified time in the future.
Futures Market	An organised market where the items traded are usually standardised contracts for specific quantities at a specified price with delivery set at a specified time in the future.
Global Indicator	Indicator measured at network level. (See also *Local Indicator*)
Grandfather Rights	A historical precedence for a series of slots an airline earns if it operates the said series of slots for a minimum percentage of the time in a previous equivalent season.
Intermediate Indicators (or Process	Indicators that provide useful information about the system (e.g., they may serve as a proxy for outcome indicators or have an influence on their evolution), but are

Concept or term	Definition
Indicators, or Surrogate Indicators)	not an objective per se. Expressing policy objectives in terms of intermediate indicators often leads to well-intentioned but ill-targeted policies. (See also *Outcome Indicator*)
Local Indicator	Indicator measured at airport level. (See also *Global Indicator*)
Market	Systems, institutions, procedures, social relations and infrastructures whereby parties engage in exchange.
Market Equilibrium	A condition where a market price is established through competition such that the amount of goods or services sought by buyers is equal to the amount of goods or services produced by sellers. The equilibrium price is often called the competitive price or market clearing price and will tend not to change unless demand or supply changes.
Model	A simplified description of a complex entity or process, often in mathematical terms, that helps conceptualise and analyse the problem.
Non-Monetary Slot Exchanges	Slot exchanges between airlines where no money is involved.
Objective Function	A function that defines the goals of an agent. Agents will try to maximise or minimise this function with its behaviour, and may even adapt/vary it to better accomplish this purpose.
Optimisation	Mathematically formulated problem whose solution is used to select a best option from a set of available alternatives.
Outcome Indicator	Indicator that measures progress towards policy objectives (i.e. the variables one wants to optimise in the system). (See also *Intermediate Indicator*)
Parameter	A variable that is assigned with a value and kept constant along a simulation. (See also *Variable*)
Passive Agent	A particular Agent not set with capability to initiate an interaction with other agents. Passive agents are included in the Agent-Based Model as they still can interact with others if they are asked, hence influencing or being influenced by the process. Stakeholders can be modelled as active/passive agents, or even both, depending on the purpose of the model/simulation. Passive agents are still agents, since they keep their autonomy and goals despite they do not influence others with them. For instance, passengers may be modelled as passive agents to analyse how they benefit from certain allocation mechanism, or active agents if they choose the airline they fly with, therefore influencing the slot demand. (See also *Agent* and *Active Agent*)
Performance Area	Broad focus area encompassing one or several goals or objectives.
Performance Framework	Set of performance areas and indicators that guide the evaluation of a particular slot allocation mechanism. (See also *Performance Area* and *Performance Indicator*)
Performance Indicator	Means of summarising the current position and the direction and rate of change of progress towards a particular goal. The use of indicators for the control and

Concept or term	Definition
	monitoring of processes helps evaluating and monitoring developments; focuses the discussion with stakeholders; promotes the idea of integrated action; demonstrates progress towards goals and objectives; and ultimately supports decision making.
Price-Setting Auction	A combinatorial iterative auction where the auctioneer sets and modifies the prices of the items as a function of demand and supply. (See also *Auction Market* and *Combinatorial Auction*)
Primary Slot Allocation (or Primary Slot Assignment)	The first stage of slot allocation process, during which most of the slots for the scheduled operations are allocated. Currently it is usually based on IATA's World Slot Guidance. (See also *Secondary Slot Allocation*)
Processing Time	Measure of time related to the real-life time which is needed to run a simulation. It depends on the ABM software implementation and the hardware used to run it. (See also *Simulated Time*)
Property file	Files used to store the configurable parameters of an application. They can also be used for storing strings for internationalisation. Each parameter is stored as a pair of strings (one storing the name of the parameter and the other storing the value of the parameter) separated by an equal sign (=).
Replica	Each execution of the same simulation scenario necessary for statistical analysis of stochastic simulations.
Rolling Capacity	A time-dependant airport capacity measure that represents a maximum number of arrival/departure/total slots available over a certain number of coordination time intervals. For instance, an airport may have 2 arrival slots available for each coordination interval, but allow only 5 arrivals as much for 3 consecutive coordination intervals (instead of 6).
Rolling Capacity Interval (or Rolling Capacity Time Interval)	The number of coordination time intervals that comprise the definition of certain rolling capacity constraint. (See also *Rolling Capacity* and *Coordination Time Interval*)
Scenario	A particular instance of the set of parameters of the model. The scenario space is composed by all possible combinations of those parameters that are relevant to, but exogenous to the model. (See also *Parameter*)
Secondary Slot Allocation (or Secondary Slot Assignment)	Second stage of the slot allocation process, where the airlines exchange slots subject to the approval of the coordinator. This is currently done in four different modalities: slot exchange without monetary compensation, slot transfers (one airline transfers the slots to another: just a transfer, without exchange), slot exchange with monetary compensation, and slot buy-sell (where this is allowed). (See also *Primary Slot Allocation*)
Simulated Time	Measure of time related to the virtual time elapsed in a simulation. Sometimes it applies to the virtual time horizon of a simulation. For instance, with some seconds of computer simulation in the real-life we might be able to virtually represent the

Concept or term	Definition
	evolution of a model over several years of simulated time. (See also *Processing Time*)
Simulation	Operation that runs certain programmed software models on computers, trying to reproduce a real-world situation over time.
Simulation time step	The time granularity of the simulated time. It is used to define the frequency of events during the simulation.
Slot	Permission given by a coordinator to use the full range of airport infrastructure necessary to operate an air service at a coordinated airport on a specific date and time for the purpose of landing or take-off.
Slot Allocation Mechanism (or Slot Assignment Mechanism)	Mechanism or scheme used to allocate slots.
Slot Trading	Exchange of slots with monetary compensation, or simple buy and sell of slots (where this is allowed).
Spot Market	A market where the items are traded for immediate delivery, typically a few days.
Stakeholder (or Actor)	A person, group or organisation that has interest or concern in slot allocation.
Stakeholder-specific Indicator	Indicator linked to a specific stakeholder or group of stakeholders. (See also *System-wide Indicator*)
System-wide (or Social) Indicators	Indicator measured at societal level. (See also *Stakeholder-specific Indicator*)
Toy Model (or Pilot Model)	A simplified model that is used to understand the fundamental mechanisms behind a complex phenomenon.
Turnaround	Period beginning when a flight arrives at an airport and ending when the aircraft takes off again. During turnaround, a defined series of actions has to be undertaken, involving both airline and airport operations as well as other parties such as ground handlers.
Variable	A quantity that varies within a simulation, as a result of its execution. (See also *Parameter*)

Table 1. Glossary of terms

1.4 Acronyms and abbreviations

Acronym	Definition
ACCESS	Application of Agent-Based Computational Economics to Strategic Slot Allocation
AE	Auction Engineering
ABM	Agent-Based Modelling
ATM	Air Traffic Management
DCA	Dynamic Combinatorial Auction
E-ATMS	European Air Traffic Management System
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
SESAR	Single European Sky ATM Research Programme
SJU	SESAR Joint Undertaking (Agency of the European Commission)

Table 2. Acronyms and abbreviations

2. Overall view of the ACCESS simulation platform

ACCESS will develop and deliver a simulation platform whose aim is to allow the evaluation of several alternative airport slot allocation mechanisms along different scenarios. Within this general aim, this toolset has several particular objectives:

- Allow the scientific study and analysis of the alternative allocation mechanisms (administrative, optimisation-based, market-based and hybrid mechanisms), their parameters and possible configurations.
- Support the interaction between realistic models of the main stakeholders (airlines, airports, slot allocation coordinator and passengers).
- The representation of different realistic scenarios corresponding to real world situations characterised by sets of exogenous factors that may have significant impact on airport slot allocation and therefore on the mechanisms supporting this process.
- Provide regulators and policy makers with a tool that facilitates the understanding of how different allocation mechanisms perform according to relevant Key Performance Indicators.
- Provide a database that can be used for further studies.

The simulation platform is specified in Section 3. This section is limited to giving a quick overview, describing the logic behind it and its main elements.

The platform consists of several main modules/components:

- A database with all the input data needed for simulation (airline characterisations, airports, demand data, scenarios configurations, additional parameters, etc.) and the output data generated after its execution.
- A graphical user interface that will allow basic users to run pre-defined scenarios and visualise the results, and administrator users to insert new elements in the database (airlines, airports, scenarios, etc.).
- A simulation engine implementing the mathematical models specified in the project, which is the core of this toolset.

The simulation core is based on Agent-Based Modelling (ABM), a methodology that allows a constructivist bottom-up approach for testing and validating complex models and systems. Following Experimental Economics research, we consider three dimensions that are essential in the design of any market experiment: i) the Institution (I), comprising the exchange rules, the way the contracts are closed and the information network; ii) the Environment (E), comprising agent endowments and values, resources, knowledge, etc.; and iii) the Agents' behaviour (A), including their objective functions, decision parameters, actions, etc. The ABM simulation engine allows the combination of these models so that the output is the result of their combined emergent behaviour, providing a means to validate a system design across different scenarios.

The simulation platform will reproduce a realistic yet simplified representation of the actual situation of the slot allocation problem. This representation involves the following three phases:

- Primary allocation, carried out before the beginning of the season.
- Secondary allocation before the beginning of the season.
- Secondary allocation along the season.

Due to the scope of the project, the time granularity selected will be a week or a month (to be determined after the first tests). A significant day of the season will be used to represent the situation of the whole season (the most congested day, a regular day, etc.). The environment will allow the simulation of a temporal horizon

corresponding to several years, long enough to replicate several primary and secondary allocations and analyse long-term effects and consequences of different mechanisms and configurations.

The simulation platform will be developed following the principles of:

- **Scientific accuracy**. The ultimate aim of ACCESS is to test alternative slot allocation mechanisms. For such study to be creditable and verifiable, scientific rigour is key. For this purpose, the set of experiments and scenarios will produce sets of output data that will be statistically analysed. The output data will be stored so it can be re-analysed in the future if necessary. This methodology is further explained in Section 2.1.
- **Modularity.** ACCESS may be the starting point of a set of more complex studies and models. The software architecture will facilitate the extension and integration of new models with the existing ones.
- **Scalability**. Due to the scope and time limitation of ACCESS project, it is expected that only relatively simple yet realistic scenarios with few airlines and airports can be simulated. The simulation platform will be developed so that bigger realistic scenarios (EU airports network and hundreds of airlines) can be also simulated.
- **Transparency**. The graphical user interface will facilitate the interaction with the tool, not requiring the user to have certain scientific and technical skills which are usually necessary for scientific simulation.

2.1 Experiment design

To accomplish the scientific analysis to be carried out in ACCESS, the simulation environment will allow the testing of different slot allocation mechanisms, showing how their impacts on a set of Key Performance Indicators (KPIs) that can be associated with policy assessment guidelines.

To carry out a strict and rigorous scientific analysis process, the use of this simulation environment will be embedded in a methodology based on the design of scientific experiments. The general structure achieved with this methodology is shown in Figure 1, where:

- The inputs of the simulation environment are the particular combination of slot allocation mechanisms to be used and their configurations, since they are the subjects of testing, and it is in the hand of the regulator/policy maker to influence or directly modify them.
- The core of the simulation is composed by all the models (most of them agent-based models) that are going to be specified and coded, such as the airlines, airports, slot coordinators, passengers, the logic of the allocation mechanisms, etc.
- Different combinations of the inputs will be simulated using the models across a set of pre-established scenarios representing different situations involving aspects not under the control of the regulator/policy maker, such as the passengers demand, the fuel price, the number of airlines in the market, the number of airports, etc. Scenarios will be arranged in experiments, where each experiment has a particular scientific aim that shall be achieved by means of a set of interrelated simulation scenarios.
- In addition, those simulations where randomness may be present shall be replicated (executed) several times to allow a statistical/stochastic analysis of the results.

The output data of the simulations is composed by a set of relevant variables influenced by the simulation. This set of output data shall be combined and/or aggregated to translate the results into a set of KPIs, to facilitate the elaboration of useful and understandable policy assessment.

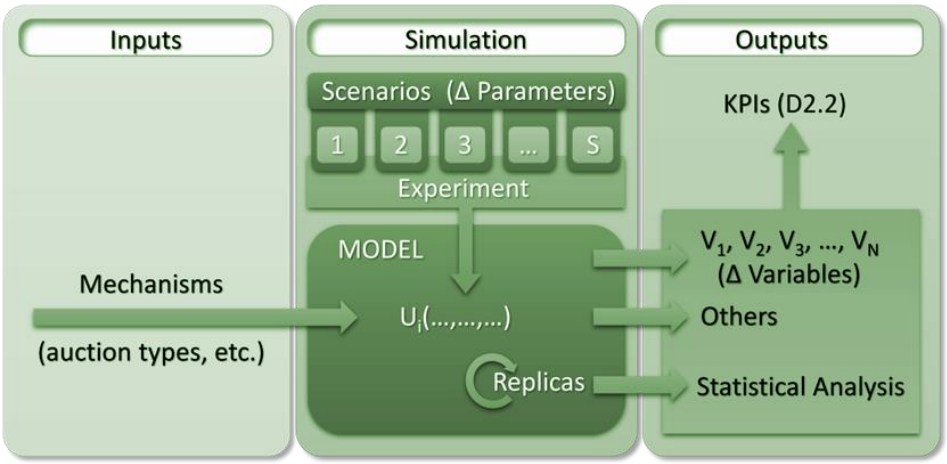


Figure 1. General structure of the ACCESS simulation process

A more detailed scheme of the experiment design process is shown in Figure 2. It can be observed how the different allocation mechanisms will be run through a combination of scenarios composed by sets of variables. Different replicas of each simulation will produce a huge amount of output data that shall be post-processed to produce understandable reports and policy assessment.

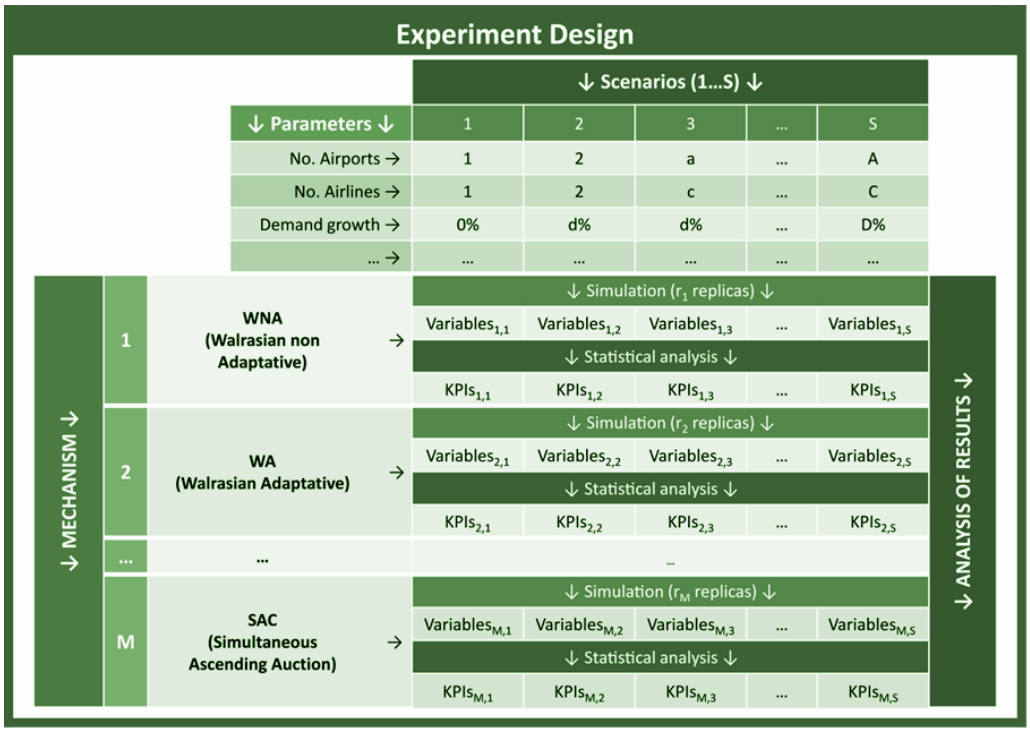


Figure 2. ACCESS experiment design

To design and configure the different auction mechanisms under test, Auction Engineering will be applied so that they will provide the expected outcome for the allocation process to optimise the set of KPIs. Lots of aspects can be distinguished and parameterised in an auction, and slight changes may lead to totally different outcomes. Experimental Economics with Agent-Based Modelling and Simulation will be applied to test, refine and validate these auction designs.

3. Technical specification

The specification is divided into four main blocks:

- User Profiles
- Front End;
- Back End;
- System Architecture.

Requirements are presented in the form of a table with the following fields:

- Id: unique identifier.
- Definition: description of a requirement or an introductory/explanatory text which is not a requirement itself. It may include links to other documents (e.g., to include formulas, drawings, etc.).
- Rationale: an explanation of the reasoning behind a requirement.
- IsReq: field indicating whether or not the main text corresponds to a requirement.
- Level: field indicating if the requirement corresponds to main functionalities of the system (high level) or if it contains information about how the system performs its functions (low level).
- Comments: any information which could be useful to understand or implement the requirement.

Id	Definition	Rationale	IsReq	Level	Comments
	USER PROFILES				
	1. User profiles		No		
	The system shall have two different user profiles: *- Common system users, which shall be able to access the system to execute simulations using pre-defined public scenarios and mechanisms.* *- Administrator users, which shall be able to access the system to execute simulations using pre-defined public scenarios and mechanisms, as well as to create new scenarios and mechanisms configurations.*		No		
ACC-REQ-111	The system shall allow all the user profiles to execute simulations using public pre-defined scenarios.		Yes	High	
ACC-REQ-111.01	The system shall implement a common user role that will be associated to every user.		Yes	Low	
ACC-REQ-111.02	The common user role shall allow the execution of simulations using public scenarios.		Yes	Low	
	1.1 Common user profile		No		
ACC-REQ-105	Each common user shall only have access to its own simulation outputs.		Yes	High	
ACC-REQ-105.01	The simulation output registry shall contain a field to associate it with the user who launched it.		Yes	Low	
ACC-REQ-105.02	The common user role shall only allow access to the simulation results associated to the concrete username of that particular user.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
	1.2 Administrator user profile		No		
ACC-REQ-110	The system shall allow the administrator users to create new scenarios.	Provides control and security to the use of the system and the data stored in it.	Yes	High	
ACC-REQ-110.01	The system shall implement an administrator role.		Yes	Low	
ACC-REQ-245	The system shall allow the administrator users to define scenarios as public or private.	Public scenarios will be available to all users whereas the private ones will only be available to administrator users.	Yes	High	
ACC-REQ-245.01	The scenarios table shall contain an attribute to identify if the scenario is public or private.		Yes	Low	
ACC-REQ-247	The system shall allow the administrator users to edit the scenarios which have been previously created by him.		Yes	High	
ACC-REQ-247.01	The scenarios table shall contain a column to identify the user who created it.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-247.02	The administrator role shall allow the edition of the scenarios created by him.		Yes	Low	
ACC-REQ-005	The system shall allow the administrator users to execute simulations using both public and private scenarios.	Public scenarios will be available to all users whereas the private ones will only be available to administrator users.	Yes	High	
ACC-REQ-005.01	The administrator role shall allow the execution of simulations using private scenarios.		Yes	Low	The execution of simulations using public scenarios are granted by common user role.
ACC-REQ-106	The system shall allow the administrator users to have access to all the outputs from every user.	Eases exchange of information and results.	Yes	High	
	FRONT END		No		
	2. Global Front End Requirements		No		
	Screenshots of the prototype are included in Annex I Front end prototype.		No		
ACC-REQ-045	All the input elements representing magnitudes shall have a label element representing the corresponding unit system of the magnitude next to it.	Avoid errors regarding magnitude/unit interpretation.	Yes	High	
ACC-REQ-045.01	Every text area representing a magnitude shall be accompanied by a label indicating the unit system.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
	3. Selection of slot allocation mechanisms		No		
	The system shall allow the simulation of a set of primary and secondary slot allocation mechanisms. *The primary slot allocation mechanisms to be simulated are the following:* *- Administrative slot allocation based on EU Regulation 95/93 and its respective amendments.* *- Optimisation-based slot allocation: mathematical integer programming model to minimise overall airspace users' costs.* *- Slot auctioning:* *- Slot auctioning using a combinatorial simultaneous ascending auction.* *- Slot auctioning using a combinatorial simultaneous descending auction.* *- Slot auctioning using a combinatorial auction with a Walrasian non-adaptive regular tâtonnement price update scheme.* *- Slot auctioning using a combinatorial auction with a Walrasian adaptive regular tâtonnement price update scheme.* *- Hybrid mechanisms:* *- Grandfather rights + optimisation-based allocation of the slot pool.* *- Grandfather rights + auctioning of the slot pool.* *The secondary slot allocation mechanisms to be simulated are the following:* *- Trading in a decentralised, over-the-counter market:* *- Non-monetary exchanges.* *- Monetary exchanges.* *- Trading in a centralised, organised market:* *- Monetary exchanges.* *The system shall allow the simulation of only a single phase as well as the simulation of the combination of one primary and one secondary slot allocation mechanism over one or several seasons.*		No		

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-002	The system shall allow the user to select the primary slot allocation mechanism among a list of available primary slot allocation mechanisms.	Allow the selection of the primary slot allocation mechanism to be simulated.	Yes	High	
ACC-REQ-002.01	The primary allocation mechanism selection shall be presented to the user using a combo box or similar selection component.		Yes	Low	
ACC-REQ-011	The system shall allow the user to select the secondary slot allocation mechanism among a list of available secondary slot allocation mechanisms.	Allow the selection of the secondary slot allocation mechanism to be simulated.	Yes	High	
ACC-REQ-011.01	The secondary allocation mechanism selection shall be presented to the user using a combo box or similar selection component.		Yes	Low	
ACC-REQ-067	The system shall allow the combination of one primary and one secondary slot allocation mechanism.	Allow the simulation of a two-stage allocation system.	Yes	High	
ACC-REQ-067.01	The secondary allocation selection component shall be used together with the primary allocation selection component.		Yes	Low	
ACC-REQ-067.02	The secondary allocation component shall be disabled until a primary allocation method will be selected.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
	3.1 Selection of primary slot allocation mechanisms		No		
ACC-REQ-012	The primary slot allocation mechanisms shall include administrative slot allocation based on EU Regulation 95/93 and its respective amendments.	Reproduce current allocation to have a baseline to compare results.	Yes	High	
ACC-REQ-012.01	The primary allocation selection component shall contain an element to allow the selection of the "administrative slot allocation".		Yes	Low	
ACC-REQ-256	The primary slot allocation mechanisms shall include mathematical integer programming models to minimise the overall airspace users' costs.	Formulation of mathematical programming models is one of the approaches identified as potentially interesting for the slot allocation problem (see ACCESS Working Paper #3).	Yes	High	
ACC-REQ-013	The primary slot allocation mechanisms shall include slot auctioning using a "combinatorial simultaneous ascending auction".	Simultaneous Ascending Auctions is one of the auction types identified as potentially interesting for the slot allocation problem (see ACCESS Working Papers #2 and #3).	Yes	High	
ACC-REQ-013.01	The primary allocation selection component shall contain an element to enable the selection of the "combinatorial simultaneous ascending auction".		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-050	The primary slot allocation mechanisms shall include slot auctioning using a "combinatorial simultaneous descending auction".	Simultaneous Descending Auctions is one of the auction types identified as potentially interesting for the slot allocation problem (see ACCESS Working Papers #2 and #3).	Yes	High	
ACC-REQ-049	The primary slot allocation mechanisms shall include slot auctioning using a "combinatorial auction with a Walrasian non-adaptive regular Tâtonnement price update scheme".	Walrasian non-adaptive regular Tâtonnement is one of the auction types identified as potentially interesting for the slot allocation problem (see ACCESS Working Papers #2 and #3).	Yes	High	
ACC-REQ-049.01	The primary allocation selection component shall contain an element to allow the selection of the "combinatorial auction with a Walrasian non-adaptive regular Tâtonnement price update scheme".		Yes	Low	
ACC-REQ-077	The primary slot allocation mechanisms shall include slot auctioning using a "combinatorial auction with a Walrasian adaptive regular Tâtonnement price update scheme".	Walrasian adaptive regular Tâtonnement is one of the auction types identified as potentially interesting for the slot allocation problem (see ACCESS Working Papers #2 and #3).	Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-072	The primary slot allocation mechanisms shall include a mechanism consisting of grandfather rights combined with optimisation-based allocation of the slot pool.	Analyse mechanisms that would imply a soft transition from the current allocation system.	Yes	High	
ACC-REQ-078	The primary slot allocation mechanisms shall include a mechanism consisting of grandfather rights combined with auctioning of the slot pool.	Analyse mechanisms that would imply a soft transition from the current allocation system.	Yes	High	
	3.1.1 Frequency of primary allocation		No		
ACC-REQ-080	The system shall allow the selection of the frequency of primary slot allocation as a time length in months.	Primary allocations frequency might be a relevant parameter of study.	Yes	High	
ACC-REQ-080.01	The default value of the primary allocation frequency shall be 6 months.		Yes	Low	
ACC-REQ-080.02	The maximum value of the primary allocation frequency shall be 240 months (20 years).		Yes	Low	
ACC-REQ-080.03	The system shall provide a component to allow the user to modify the default frequency of the slot allocation.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
	3.1.2 Auction configuration		No		
	3.1.2.1 Price update parameters		No		
	When the primary slot allocation mechanism is based on auctions, there are several parameters that have to be specified by the auctioneer, regardless of the specific auction type to be used. These are: *- The initial auction prices/multipliers (depending on the price update mechanism).* *- Whether participants are allowed not to bid for a certain number of rounds and, if so, for how many.* *- The parameters of the price update algorithm, namely: i) the initial percentage applied to increase/decrease prices/multipliers, ii) the frequency (number of iterations) with which the price/multiplier update percentage (i.e. the percentage applied to increase/decrease prices/multipliers) is modified (to help price convergence, the price variation percentage is reduced every certain number of rounds. Example: 50% every 5 rounds); and iii) the percentage applied to modify the price/multiplier update percentage (the price/multiplier variation percentage is scaled by this factor with a certain frequency).* *The system shall allow the user to choose the above parameters (or use some default values), as these can be relevant for the outcome of the auctions and it is therefore interesting to test the effect of varying them.* *The prices are calculated by means of certain combination of multipliers, whose values depend on the capacity constraints violations. The mathematical expressions linking these parameters are detailed in Annex III "Combinatorial Auction Mechanism" (Step 4).*		No		
ACC-REQ-046	Default initial slot prices/multipliers in ascending auctions shall be 0 for every slot.	Prices can only be increased during the auction.	Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-046.01	Default initial slot prices in ascending auctions shall be 0 for every slot.		Yes	Low	
ACC-REQ-046.02	Default initial multiplier in ascending auctions shall be 0 for every slot.		Yes	Low	
ACC-REQ-134	Default initial slot prices/multipliers in descending auctions shall be TBD for every slot.	Prices can only be decreased during the auction.	Yes	High	The right value will be determined after some preliminary testing. The value shall be high enough so that prices are then decreased depending on demand until they converge to their final value.
ACC-REQ-135	Default initial slot prices/multipliers in Walrasian auctions shall be 0 for every slot.	Prices can be increased or decreased depending on capacity and demand.	Yes	High	
ACC-REQ-135.01	Default initial slot prices in ascending auctions shall be 0 for every slot.		Yes	Low	
ACC-REQ-135.02	Default initial multiplier in ascending auctions shall be 0 for every slot.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-047	The system shall allow the selection of whether auction initial prices/multipliers are set from default values or are based on the prices/multipliers of previous allocations.	The user can choose whether to use default prices (different for each auction mechanism) or use prices based on previous allocations (this would be expected to shorten the auction process).	Yes	High	
ACC-REQ-047.01	The data repository shall store the prices established at the end of each auction.		Yes	Low	
ACC-REQ-047.02	The user shall be able to choose the starting prices for every auction: default prices or the ones established at the end of the previous auction.		Yes	Low	
ACC-REQ-047.03	The data repository shall store the multipliers established at the end of each auction.		Yes	Low	
ACC-REQ-047.04	The user shall choose starting multipliers for all auctions: default multiplier or the ones established at the end of the previous auction.		Yes	Low	
ACC-REQ-051	Default initial slot prices/multipliers shall be used if no other initial prices are specified.	If there are no previous prices or the user doesn't want to use them, initial auction prices will be the default prices of the auction mechanism.	Yes	High	
ACC-REQ-051.01	The user shall be able to edit the values of the slot prices.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-051.02	The user shall be able to edit the values of the multipliers.		Yes	Low	
ACC-REQ-208	In the simultaneous ascending auction, the maximum number of rounds during which a participant remains inactive shall be TBD.	A bidder remains active if the prices of its currently requested slots have not changed. Participants may decide not to bid for any slot depending on their costs and utility. After this maximum number of rounds of inactivity, the participant shall not be allowed to make more requests in the auction.	Yes	High	
ACC-REQ-208.01	The default maximum number of inactive rounds for a participant shall be 0.		Yes	Low	
ACC-REQ-208.02	The system shall provide a component to allow the user to modify the default maximum number of inactive rounds for a participant.		Yes	Low	
ACC-REQ-090	In auctions where prices may rise, the user shall be able to select the value of the initial percentage applied to increase prices/multipliers.	The optimum value should be a parameter under study.	Yes	High	
ACC-REQ-090.01	The initial percentage applied to increase prices shall be a percentage with two decimal places.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-090.02	The system shall provide a component to allow the user to modify the initial percentage applied to increase prices.		Yes	Low	
ACC-REQ-091	In auctions where prices may rise, the initial percentage applied to increase prices/multipliers shall have a default value of TBD%.	The optimum value should be a parameter under study.	Yes	High	
ACC-REQ-091.01	The default initial percentage applied to price increase shall be 20%.		Yes	Low	
ACC-REQ-092	In auctions where prices may decrease, the user shall be able to select the value of the initial percentage applied to reduce prices/multipliers.	The optimum value should be a parameter under study.	Yes	High	
ACC-REQ-093	In auctions where prices may decrease, the initial percentage applied to reduce prices/multipliers shall have a default value of TBD%.	The optimum value should be a parameter under study.	Yes	High	
ACC-REQ-096	The user shall be able to select the value of the frequency with which the price/multiplier update percentage is modified.	The optimum value should be a parameter under study.	Yes	High	
ACC-REQ-096.01	The system shall store the frequency with which the price update percentage is modified in an integer variable.		Yes	Low	
ACC-REQ-096.02	The system shall provide a component to allow the user to modify the price update percentage.		Yes	Low	
ACC-REQ-096.03	The system shall store frequency with which the multiplier update percentage is modified in an integer variable.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-096.04	The system shall provide a component to allow the user to modify the multiplier update percentage.		Yes	Low	
ACC-REQ-097	The frequency with which the price/multiplier update percentage is modified shall have a default value of TBD rounds.	The optimum value should be a parameter under study. This will modify both the incremental and decremental percentages at the same time.	Yes	High	
ACC-REQ-097.01	The frequency with which the price update percentage is modified shall be an integer variable.		Yes	Low	
ACC-REQ-097.02	The default value of the frequency with which the frequency with which the price update percentage is modified shall be 10 rounds.		Yes	Low	
ACC-REQ-097.03	The system shall provide a component to allow the user to modify the frequency with which the price update percentage is modified.		Yes	Low	
ACC-REQ-098	The user shall be able to select the value of the percentage applied to modify the price/multiplier update percentage.	The optimum value should be a parameter under study.	Yes	High	
ACC-REQ-098.01	The percentage applied to modify the price shall be an integer variable.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-098.02	The system shall provide a component to allow the user to modify the percentage applied to modify the price.		Yes	Low	
ACC-REQ-094	The percentage applied to modify the price/multiplier update percentage shall have a default value of 50%.	The optimum value should be a parameter under study.	Yes	High	
ACC-REQ-094.01	The default value of the percentage applied to modify the price shall be 50%.		Yes	Low	
	3.1.2.2 Auction stop criteria		No		
	The auction mechanisms to be tested in ACCESS are iterative processes. Hence, a criterion to stop them needs to be defined. The user shall be able to choose one or several among the following: *- C1. A maximum number of rounds has been performed.* *- C2. Prices do not vary more than a convergence threshold between rounds.* *- C3. All the capacity constraints are fulfilled.* *When several stop criteria are specified, it shall be specified the way to combine them. The possible combinations are:* *- C1 OR C2.* *- C1 OR C3.* *- C2 OR C3.* *- C2 AND C3.* *- C1 OR (C2 AND C3).* *- C1 OR (C2 OR C3).*		No		

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-082	The auctions' stop criteria shall include to stop the auction when a maximum number of rounds is reached (C1).	Stop the auction after certain number of rounds, limiting its duration.	Yes	High	
ACC-REQ-082.01	The system shall contain a boolean variable to infer when the maximum number of rounds is reached.		Yes	Low	
ACC-REQ-083	The auctions' stop criteria shall include to stop the auction when prices do not vary more than a convergence threshold between two consecutive rounds (C2).	Stop the auction if a market equilibrium situation (or close to it) has been achieved.	Yes	High	
ACC-REQ-083.01	The system shall contain a boolean variable to infer when prices do not vary more than a convergence threshold between two consecutive rounds.		Yes	Low	
ACC-REQ-084	The auctions' stop criteria shall include to stop the auction as soon as airports' capacity restrictions are not violated (C3).	Stop the auction as soon as some feasible allocation is found, despite it might not be an optimum solution.	Yes	High	
ACC-REQ-084.01	The system shall contain a boolean variable to infer when airports' capacity restrictions are not violated.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-085	The system shall allow the selection of the stop criterion to be applied to iterative auctions among the following options: - C1. - C2. - C3. - C1 OR C2. - C1 OR C3. - C2 OR C3. - C2 AND C3. - C1 OR (C2 AND C3). - C1 OR (C2 OR C3).	Both, a single criterion or a combination of several criteria, could be selected.	Yes	High	
ACC-REQ-085.01	The system shall provide a control to allow the user to select simple and combined stop criterions.		Yes	Low	
	3.1.2.3 Feasibility of auction results and tie-breaking		No		
	At certain situations, an auction could end before all the capacity constraints are fulfilled, preventing the obtainment of feasible allocations after the auction. In these situations, some airlines will be tied and a way to break these ties and exclude certain flights for making the allocation feasible is needed. The user shall be able to choose one tie-breaking criterion among the following: *- Prioritising the most expensive combinations (the corresponding airline's bid with the highest amount paid for the combination of arrival and departure slots).* *- Prioritising requests composed by a higher/lower number of slots.* *- Random prioritisation.*		No		

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-052	The system shall allow the selection of a mechanism to break auction ties from a list.	Several prioritizations might be applied to break auction ties. One or several shall be selected to be applied.	Yes	High	
ACC-REQ-131	The list of mechanisms to break auction ties shall include the option "Tie-breaking by prioritising higher auction costs", prioritising the higher bids for the set [arrival slot, departure slot].	Prioritise requests with more expensive slots.	Yes	High	
ACC-REQ-130	The list of mechanisms to break auction ties shall include the option "Tie-breaking by prioritising those requests composed by a higher/lower number of slots".	Prioritisation of requests with more slots could help to optimise the whole allocation, but may favour big airlines at hub airports. Prioritisation of requests with few slots may help small airlines to acquire more slots.	Yes	High	
ACC-REQ-133	The list of mechanisms to break auction ties shall include the option "Random tie-breaking".	Provide a way to break ties without prioritising and/or when all other criteria have not been useful.	Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
	3.2 Selection of secondary slot allocation mechanisms		No		
ACC-REQ-017	The secondary slot allocation mechanisms shall include slot trading in a decentralised over-the-counter market with non-monetary slot exchanges.	To allow a decentralised secondary market where airlines bargain freely, with no monetary compensations for the slots traded.	Yes	High	Over-the-counter (OTC) trading is done directly between two parties, without any supervision. This is different from an organised market, e.g. an airline may want to sell slots only to a limited group of buyers. Non-monetary exchanges may be less relevant than monetary exchanges (and therefore left out of a first iteration) or even not necessary (and therefore removed after the analysis phase).
ACC-REQ-016	The secondary slot allocation mechanisms shall include slot trading in a decentralised over-the-counter market with monetary slot exchanges.	To allow a decentralised secondary market where airlines bargain freely, with monetary compensations for the slots traded based on the current slot prices.	Yes	High	
ACC-REQ-014	The secondary slot allocation mechanisms shall include slot trading in a centralised organised market with monetary slot exchanges.	To allow a centralised secondary market based on auctions where prices may change.	Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-014.01	The secondary allocation selection component shall contain an element to enable the selection of the "slot trading in a centralised organised market".		Yes	Low	
	4. Scenario creation and selection		No		
	A scenario is a particular instance of the set of parameters of the model. Generally, the scenario specification includes parameters which are not under direct control of the agents but would produce relevant situations to be studied. *A scenario shall consist of a particular instance of the following parameters:* *- Set of airports to be simulated. Airports shall be selected from a list of pre-defined airports.* *- Set of airlines to be simulated. Airlines shall be selected from a list of pre-defined airlines.* *- Temporal horizon of the simulation.* *- Simulation time step.* *- Evolution of air travel demand.* *- Evolution of fuel costs.* *- Possibility of airport capacity expansion.* *- Possibility of airport landing fees modification.* *- Possibility of airlines fleet expansion.*		No		
	4.1 Scenario item creation		No		
	Some of the parameters of the scenarios (airlines, airports and aircrafts) are complex and have sub-parameters of their own that need to be configured and therefore editable.		No		

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-164	The system shall allow the administrator user to create and store airline, airport and aircraft configurations to be used in the scenario definition.		Yes	High	
ACC-REQ-164.01	The system shall provide a specific view to allow the administrator user the creation of new airline entities.		Yes	Low	
ACC-REQ-164.02	The system shall provide a specific view to allow the administrator user the creation of new airport entities.		Yes	Low	
ACC-REQ-164.03	The system shall provide a specific view to allow the administrator user the creation of new aircraft entities.		Yes	Low	
ACC-REQ-164.04	The system shall provide a specific view to allow the administrator user the creation of new turnaround entities.		Yes	Low	
ACC-REQ-164.05	The system shall provide a specific view to allow the administrator user the creation of new airline alliance entities.		Yes	Low	
ACC-REQ-165	The system shall allow the administrator user to view and edit previously created airline, airport and aircraft configurations to be used in the scenario definition.		Yes	High	
ACC-REQ-165.01	The system shall allow the administrator user to view previously created airline entities.		Yes	Low	
ACC-REQ-165.02	The system shall allow the administrator user to view previously created airport entities.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-165.03	The system shall allow the administrator user to view previously created aircraft entities.		Yes	Low	
ACC-REQ-165.04	The system shall allow the administrator user to view previously created turnaround entities.		Yes	Low	
ACC-REQ-165.05	The system shall allow the administrator user to view previously created airline alliance entities.		Yes	Low	
ACC-REQ-165.06	The system shall allow the administrator user to edit previously created airline entities.		Yes	Low	
ACC-REQ-165.07	The system shall allow the administrator user to edit previously created airport entities.		Yes	Low	
ACC-REQ-165.08	The system shall allow the administrator user to edit previously created aircraft entities.		Yes	Low	
ACC-REQ-165.09	The system shall allow the administrator user to edit previously created turnaround entities.		Yes	Low	
ACC-REQ-165.10	The system shall allow the administrator user to edit previously created airline alliance entities.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
	4.1.1 Airport creation and modification		No		
	The system shall allow the administrator users to define and modify airport parameters.		No		
ACC-REQ-248	The system shall allow the administrator users to define and modify the airport name.		Yes	High	
ACC-REQ-248.01	The name of the airport entity shall be represented using a text field.		Yes	Low	
ACC-REQ-249	The system shall allow the administrator users to define and modify the airport identifier.		Yes	High	
ACC-REQ-249.01	The identifier of the airport entity shall be represented using a text field.		Yes	Low	
ACC-REQ-292	The system shall allow the administrator users to define and modify the airport position using longitude and latitude values.		Yes	High	
ACC-REQ-292.01	The position of the airport entity shall be represented using two text fields, one for longitude and one for latitude.		Yes	Low	
ACC-REQ-293	The system shall allow the administrator users to select and modify the airport type from a list taking one of the following values: "Primary" or "Secondary".		Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-293.01	The position of the airport entity shall be represented as a radio button selector with two fields "Primary" and "Secondary".		Yes	Low	
ACC-REQ-246	The system shall allow the administrator users to select and modify the airport level from a list taking one of the following values: "Non-coordinated", "Schedules facilitated" or "Coordinated".		Yes	High	
ACC-REQ-246.01	The position of the airport entity shall be represented using a selection list with three possible values: "Non-coordinated", "Schedules facilitated" or "Coordinated".		Yes	Low	
ACC-REQ-254	The system shall allow the administrator users to define and modify the airport coordination time interval.		Yes	High	
ACC-REQ-254.01	The coordination time interval of the airport entity shall be represented using a selection list.		Yes	Low	
ACC-REQ-227	The system shall allow the administrator users to define and modify the airport landing fees.		Yes	High	
ACC-REQ-277.01	The landing fees of the airport entity shall be represented using a table containing multiple text fields. One dimension of this table shall be the corresponding coordination interval and the other one the complete set of aircrafts defined within the system.		Yes	Low	
ACC-REQ-232	The system shall allow the administrator users to define and modify the airport opening hour.		Yes	High	
ACC-REQ-277.01	The opening hour of the airport entity shall be represented using a text field.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-237	The system shall allow the administrator users to define and modify the airport closing hour.		Yes	High	
ACC-REQ-237.01	The closing hour of the airport entity shall be represented using a text field.		Yes	Low	
ACC-REQ-276	The system shall allow the administrator users to define and modify the airport arrival capacity.		Yes	High	
ACC-REQ-276.01	The arrival capacity of the airport entity shall be represented using a table containing multiple text fields.		Yes	Low	
ACC-REQ-290	The system shall allow the administrator users to define and modify the airport departure capacity.		Yes	High	
ACC-REQ-290.01	The departure capacity of the airport entity shall be represented using a table containing multiple text fields.		Yes	Low	
ACC-REQ-279	The system shall allow the administrator users to define and modify the airport infrastructure capacity.		Yes	High	
ACC-REQ-279.01	The infrastructure capacity of the airport entity shall be represented using a table containing multiple text fields.		Yes	Low	
ACC-REQ-280	The system shall allow the administrator users to define and modify the airport rolling capacity time interval.		Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-280.01	The rolling capacity time interval of the airport entity shall be represented using a selection list.		Yes	Low	
ACC-REQ-282	The system shall allow the administrator users to define and modify the airport rolling arrival capacity.		Yes	High	
ACC-REQ-282.01	The rolling arrival capacity of the airport entity shall be represented using a table containing multiple text fields.		Yes	Low	
ACC-REQ-283	The system shall allow the administrator users to define and modify the airport rolling departure capacity.		Yes	High	
ACC-REQ-283.01	The rolling departure capacity of the airport entity shall be represented using a table containing multiple text fields.		Yes	Low	
ACC-REQ-284	The system shall allow the administrator users to define and modify the airport rolling infrastructure capacity.		Yes	High	
ACC-REQ-284.01	The rolling infrastructure capacity of the airport entity shall be represented using a table containing multiple text fields.		Yes	Low	
ACC-REQ-286	The system shall allow the administrator users to select and modify if the airport capacity expansion is possible or not.		Yes	High	
ACC-REQ-286.01	The capacity expansion of the airport entity shall be represented using a checkbox component.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-179	The system shall allow the administrator users to select and modify if the airport landing fee modification is possible or not.		Yes	High	
ACC-REQ-179.01	The landing fee modification of the airport entity shall be represented using a checkbox component.		Yes	Low	
ACC-REQ-301	The system shall allow the administrator users to select and modify if the grandfather rights		Yes	High	
ACC-REQ-301.01	The grandfather rights of the airport entity shall be represented using a table containing multiple text fields.		Yes	Low	
	4.1.2 Airline creation and modification		No		
	The system shall allow the administrator users to define and modify airline parameters.		No		
ACC-REQ-132	The system shall allow the administrator users to define and modify the airline name.		Yes	High	
ACC-REQ-132.01	The name of the airline entity shall be represented using a text field.		Yes	Low	
ACC-REQ-161	The system shall allow the administrator users to define and modify the airline identifier.		Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-161.01	The identifier of the airline entity shall be represented using a text field.		Yes	Low	
ACC-REQ-163	The system shall allow the administrator users to select and modify the airline business model from a list taking one of the following values: "Network", "Low Cost", "Regional", "Charter" or "Cargo".		Yes	High	
ACC-REQ-163.01	The business model of the airline entity shall be represented in a selection list with five possible values: "Network", "Low Cost", "Regional", "Charter" or "Cargo".		Yes	Low	
ACC-REQ-162	The system shall allow the administrator users to define and modify the airline hubs from a list of airports.		Yes	High	
ACC-REQ-162.01	The hubs of the airline entity shall be represented using a multiselection list made up by all the airports defined in the system. The hub airports of the airline shall be the selected elements on the list.		Yes	Low	
ACC-REQ-180	The system shall allow the administrator users to add and remove aircrafts to the airline fleet.		Yes	High	
ACC-REQ-180.01	The aircrafts which belongs to the airline entity shall be represented using a table. The system will allow to assign a new aircraft type to the airline and the number of them that belongs to it.		Yes	Low	
ACC-REQ-171	The system shall allow the administrator users to define and modify the airline operational cost factors.		Yes	High	
ACC-REQ-171.01	The indirect operational costs of the airline instance shall be represented using a text field.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-171.02	The direct cost of the airline instance shall be presented using a table which shows the fleet representation of the airline.		Yes	Low	
ACC-REQ-172	The system shall allow the administrator users to select and modify the airline alliance from a list of pre-defined alliances.		Yes	High	One company belongs to none or one alliance.
ACC-REQ-172.01	The alliance which the airline entity belongs to shall be presented using a selection list which shall include the identifiers of the alliances defined in the system.		Yes	Low	
ACC-REQ-173	The system shall allow the administrator users to select and modify if the airline fleet modification is allowed or not.		Yes	High	
ACC-REQ-173.01	The fleet modification of the airline entity shall be represented using a checkbox component		Yes	Low	
	4.1.3 Aircraft creation and modification		No		
	The system shall allow the administrator users to define and modify aircraft parameters.		No		
ACC-REQ-166	The system shall allow the administrator users to define and modify the aircraft identifier.		Yes	High	
ACC-REQ-166.01	The identifier of the aircraft entity shall be represented using a text field.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-167	The system shall allow the administrator users to define and modify the aircraft seating capacity.		Yes	High	
ACC-REQ-167.01	The seating capacity of the aircraft entity shall be represented using a text field.		Yes	Low	
ACC-REQ-273	The system shall allow the administrator users to define and modify the aircraft cruise speed.		Yes	High	
ACC-REQ-273.01	The cruise speed of the aircraft entity shall be represented using a text field.		Yes	Low	
ACC-REQ-158	The system shall allow the administrator users to define and modify the aircraft fuel consumption.		Yes	High	
ACC-REQ-158.01	The fuel consumption of the aircraft entity shall be represented using a text field.		Yes	Low	
ACC-REQ-144	The system shall allow the administrator users to define and modify the Aircraft Average Block Hour Direct Operating Cost (BHDOC).		Yes	High	
ACC-REQ-144.01	The Aircraft Average Block Hour Direct Operating Cost (BHDOC) of the aircraft entity shall be represented using a text field.		Yes	Low	
ACC-REQ-299	The system shall allow the administrator users to define and modify the Range.		Yes	High	
ACC-REQ-299.01	The Range of the aircraft entity shall be represented using a text field.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
	4.1.4 Turnaround definition		No		
ACC-REQ-103	The system shall allow the administrator users to define and modify the turnaround time for each triad (aircraft type, airport, and airline).		Yes	High	
ACC-REQ-103.01	The turnaround times should be presented using a table in the airline UI, on one axis will be the aircraft models defined in the system and in the other one the airports.		Yes	Low	
	4.2 Scenario creation and modification		No		
ACC-REQ-055	The system shall allow the administrator users to select and modify the set of airports to be included in each scenario from a list of pre-defined airports.	Define the scope and range of the auction process in the simulation.	Yes	High	
ACC-REQ-055.01	The airports included in the scenario shall be represented in multiselection list.		Yes	Low	
ACC-REQ-056	The system shall allow the administrator users to select and modify the set of airlines to be included in each scenario from a list of pre-defined airlines.	Determine the number and types of airlines that will enter the auction process and request slots at the airports.	Yes	High	
ACC-REQ-056.01	The airlines included in the scenario shall be represented in multiselection list.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-079	The system shall allow the administrator users to define and modify the time horizon of each scenario ("simulated time").	Simulate a certain period of time and stop after that.	Yes	High	"Simulated time" is related to a virtual time horizon, i.e. 10 years until 2024. Be aware of not confusing it with "processing time", which shall be understood as the time we need in real life to execute certain simulation in a computer.
ACC-REQ-079.01	The time horizon of the scenario instance shall be presented using a selection list.		Yes	Low	
ACC-REQ-068	The system shall allow the simulation of allocation mechanisms along a period of at least 20 years.	Allow the study of the impact of an allocation mechanism when it is iterated over time. 20 years is the horizon of EUROCONTROL (STATFOR) traffic forecast and has been taken for convenience.	Yes	High	
ACC-REQ-068.01	The maximum value of the time horizon shall be 20 years.		Yes	Low	
ACC-REQ-194	The system shall allow the administrator users to define and modify the simulation time step of each scenario.	Allow different levels of simulation time granularity, e.g. airlines may reconsider their schedule every week, every month, every year, etc.	Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-194.01	The simulation time step of the scenario entity shall be presented using a selection list.		Yes	Low	
ACC-REQ-086	The system shall allow the administrator users to define and modify the demand for the origin-destination pairs of each scenario.	Allow the configuration of different demand level scenarios.	Yes	High	
ACC-REQ-086.01	The demand for origin-destination pairs shall be represented using an editable table.		Yes	Low	
ACC-REQ-112	The system shall allow the administrator users to define and modify the demand volatility for each scenario.	Model the uncertainty in demand forecast.	Yes	High	
ACC-REQ-112.01	The demand volatility shall be presented using a selection list with three values: "High", "Medium", and "Low".		Yes	Low	
ACC-REQ-088	The system shall allow the administrator users to select and modify the evolution of fuel price in each scenario from a list of pre-defined fuel price evolution profiles.	Allow the configuration of different fuel prices scenarios.	Yes	High	
ACC-REQ-088.01	The evolution of fuel price shall be presented using a selection list with four values: "High increase", "Medium increase", "Low increase", and "Steady".		Yes	Low	
ACC-REQ-145	The system shall allow the administrator users to define and modify the fuel price volatility for each scenario.	Model the uncertainty in fuel price forecast.	Yes	High	
ACC-REQ-145.01	The fuel price volatility shall be represented using a selection list with three values: "High", "Medium", and "Low".		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-113	For each scenario, the system shall allow the administrator users to specify and modify whether airports may vary their capacity or not.	An aspect that should be taken into account when evaluating a certain airport slot allocation system is its ability to create the right incentives for investment. Increases in airport capacity devaluate slots. Some authors argue that auctions could create perverse incentives for airports to underinvest in new capacity if they make profits from pricing or auctioning of scarce capacity. On the other hand, it is also reasonable to argue that, with the current system, incumbent airlines that have very valuable slots at busy airports have an incentive to moderate their requests for capacity expansion (see ACCESS Working Paper #3).	Yes	High	
ACC-REQ-113.01	The airport capacity expansion shall be presented using a check controller.		Yes	Low	
ACC-REQ-177	For each scenario, the system shall allow the administrator users to specify and modify whether airports may update landing fees profile.	Provision for future evolution of the tool allowing the simulation of pricing strategies	Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-177.01	The changes in the landing fees shall be presented using a check controller.		Yes	Low	
ACC-REQ-197	For each scenario, the system shall allow the administrator users to specify and modify whether airlines may modify their fleet.	Provision for future evolution of the tool allowing the simulation of fleet expansion/renewal strategies.	Yes	High	
ACC-REQ-197.01	The modification of the airlines' fleet shall be presented using a check controller.		Yes	Low	
ACC-REQ-003	The system shall allow the administrator users to define and modify whether the scenario configuration will be publicly available to all the system users.	Allow the administrator users to create public and private scenario definitions.	Yes	High	
ACC-REQ-003.01	The modification of the airlines' fleet shall be presented using a selection list or a radio button with two values: "Yes" or "No".		Yes	Low	
ACC-REQ-302	The system shall allow the administrator users to define and modify the description of the scenario.	Allow the administrator users to create public and private scenario definitions.	Yes	High	
ACC-REQ-302.01	The description of the scenario shall be presented using a text area.		Yes	Low	
	4.3 Scenario selection		No		
ACC-REQ-015	The system shall allow the user to select a scenario from a list of pre-defined scenarios.	The creation of meaningful scenarios is a complex task that shall only be performed by system administrators.	Yes	High	
ACC-REQ-015.01	The complete list of public and owned scenarios shall be presented using a selection list.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
	5. Simulation specification		No		
	The user shall be able to define the parameters needed to properly configure a simulation.		No		
ACC-REQ-004	The system shall allow the user to select the number of replicas to be run for each simulation.	Allow the statistical analysis of parameters across several replicas of the same simulation.	Yes	High	
ACC-REQ-004.01	The number of replicas shall be presented using a selection list.		Yes	Low	
ACC-REQ-176	The system shall allow the user to specify a maximum processing time after which a simulation shall stop.	Establish an end for every simulation.	Yes	High	"Processing time" is the time we need in real life to execute certain simulation in a computer. It should not be confused with "Simulated time", which is related to a virtual time horizon, i.e. 10 years until 2024, which is simulated by the tool.
ACC-REQ-176.01	The maximum processing time shall be represented using a selection list.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
	6. Simulation outputs		No		
	Simulation outputs include all the data which shall be produced by a simulation and that are necessary for further analysis. Simulation outputs shall include: *- Data on available slots, slot requests, slot prices, slot allocation and slot use.* *- A set of performance indicators allowing the comparison of different slot allocation mechanisms.* *Output data shall be stored so that the analysis can be reproduced or extended in the future, if needed.*				
ACC-REQ-281	The system shall allow the user to download all the simulation raw data and outputs for further study in a text file.		Yes	High	The structure and format of this file shall be determined in the future.
ACC-REQ-281.01	Each simulation results view shall include a control to allow the download of raw data using a CSV formatted file.		Yes	Low	
	6.1 Available slots, slot requests, slot prices, slot allocation and slot use		No		
ACC-REQ-119	Simulation output data shall include the number of slots available at each coordinated airport during each coordination interval of each simulated season.		Yes	High	
ACC-REQ-119.01	The system shall maintain a historic record of the slots used at each coordinated airport for each simulated season.		Yes	Low	
ACC-REQ-182	Simulation output data shall include the slots that would be requested by each airline in each coordination interval for every simulated primary slot allocation process if the price of all slots were 0.	Compare the final allocation with the original preferences of the airlines.	Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-182.01	The system shall maintain a historic record of the slots requested by each airline at the first iteration of the slot allocation process.		Yes	Low	
ACC-REQ-204	Simulation output data shall include the price of the slots at each coordinated airport in each coordination interval during each simulated season.		Yes	High	
ACC-REQ-204.01	The system shall maintain a historic record of the prices of the slots at each coordinated airports in each coordination interval during each simulated season.		Yes	Low	
ACC-REQ-122	Simulation output data shall include the final slot allocation for every coordinated airport during each simulated season.		Yes	High	
ACC-REQ-122.01	The system shall maintain a historic record of the final slot allocation for every coordinated airport during each simulated season.		Yes	Low	
ACC-REQ-123	Simulation output data shall include the final slot allocation for every airline during each simulated season.		Yes	High	
ACC-REQ-123.01	The system shall include the airline who has obtained rights of use of each slot in the historic record of the final slot allocation.		Yes	Low	
ACC-REQ-203	Simulation output data shall include the slot use by every airline during each simulated season.		Yes	High	
ACC-REQ-203.01	The system shall include if the airline has used each slot in the historic record of the final slot allocation.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
	6.1.1 Intermediate indicators for auction-based primary allocation		No		
ACC-REQ-120	If primary allocation is based on auctions, simulation output data shall include slot prices for every round of every auction carried out.	Allow the representation of slot prices evolution.	Yes	High	
ACC-REQ-120.01	When auction-based allocation mechanisms are used, the system shall maintain an historic record of the slot prices on every round of the auction.		Yes	Low	
ACC-REQ-138	If primary allocation is based on auctions, simulation output data shall include the slot allocation for every airport at the end of the auction (before executing the feasibility process).	Analyse the performance of the auction mechanism.	Yes	High	The feasibility process is described in section 9.1.3.6
ACC-REQ-138.01	When auction-based allocation mechanisms are used, the system shall maintain a historic record of the final slot allocation at the end of each auction for every coordinated airport during each simulated season.		Yes	Low	
ACC-REQ-202	If primary allocation is based on auctions, simulation output data shall include the schedule for every airline at the end of the auction (before executing the feasibility process).	Analyse the performance of the auction mechanism.	Yes	High	The feasibility process is described in section 9.1.3.6
ACC-REQ-202.01	When auction-based allocation mechanisms are used, the system shall include in the historic record of the final slot allocation the airline that have obtained rights over each slot.		Yes	Low	
ACC-REQ-274	If primary allocation is based on auctions, simulation output data shall include auctions' economic outcome, calculated as the sum of the economic amounts paid for every slot allocated at every airport.		Yes	High	
ACC-REQ-274.01	When auction-based allocation mechanisms are used, the system shall maintain an historic record of the auctions' economic outcome.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
	6.2 Performance indicators		No		
	6.2.1 Economic efficiency indicators		No		
ACC-REQ-114	Simulation output data shall include the total utility obtained by all stakeholders, calculated as the sum of the utilities obtained by the airlines, the airports, the slot allocation coordinator and the passengers.	The total utility can be related to the "social welfare". Maximising total utility can be related to an improvement of the "social welfare".	Yes	High	
ACC-REQ-114.01	The system shall maintain an historic record of the utilities obtained by the airlines, the airports, the slot allocation coordinator and the passengers.		Yes	Low	
	6.2.2 Equity indicators		No		
ACC-REQ-115	Simulation output data shall include the utility obtained by each airline from slot use, calculated as the profit realised for all the flights included in the airline's "Actual Schedule" during each simulated season.	Maximum overall utility could be achieved at the expense of some individual airlines that can be enormously more penalised than others, thus negatively affecting equity (see ACCESS Working Paper #3).	Yes	High	
ACC-REQ-115.01	The system shall maintain a historic record of the actual use (number of flights) of each record by the airlines.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-126	Simulation output data shall include the utility obtained by passengers for each origin-destination pair during each simulated season.	Maximum overall utility could be achieved at the expense of some regions, whose accessibility may be reduced, thus negatively affecting equity (see ACCESS Working Paper #3).	Yes	High	
ACC-REQ-126.01	The system shall maintain a historic record of the utility obtained by the passengers for each pair origin-destination during each simulated season.		Yes	Low	
	6.2.3 Access and competition indicators		No		
ACC-REQ-116	Simulation output data shall include the maximum percentage of slots owned by a single airline at each coordinated airport.	Slot concentration may increase the risk of anticompetitive behaviours such as exclusionary conducts and mergers, which has sometimes led regulators to take measures to limit such concentration (see ACCESS Working Paper #3).	Yes	High	Some authors argue that measuring slot concentration as an indicator of competition could be misleading, as it may happen that the maximisation of social welfare occurs for a high level of concentration of slots at certain airports, which could be due to the value of slots in a hub and spoke network (see ACCESS Working Paper #3).

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-222	Simulation output data shall include the maximum percentage of slots owned by a single airline alliance at each coordinated airport.	Slot concentration may increase the risk of anticompetitive behaviours such as exclusionary conducts and mergers, which has sometimes led regulators to take measures to limit such concentration (see ACCESS Working Paper #3).	Yes	High	Some authors argue that measuring slot concentration as an indicator of competition could be misleading, as it may happen that the maximisation of social welfare occurs for a high level of concentration of slots at certain airports, which could be due to the value of slots in a hub and spoke network (see ACCESS Working Paper #3).
	6.2.4 Capacity indicators		No		
ACC-REQ-118	Simulation output data shall include the capacity of each coordinated airport during each simulated season.	Different slot allocation systems may create different incentives for investment in capacity. Since increases in airport capacity devaluate slots, some authors argue that auctions could create perverse incentives for airports to underinvest in new capacity if they make profits from auctioning of scarce capacity (see ACCESS Working Paper #3).	Yes	High	
	7. Analysis and visualisation of results		No		

Id	Definition	Rationale	IsReq	Level	Comments
	The system shall allow the representation of simulations' output data. Besides, simulation output data shall be further processed to produce useful information easy to interpret by regulators and/or policy makers, which will mainly involve the following operations, or a combination of them: *- Statistical analysis.* *- Combination of several output data.* *- Graphical representations.*		No		
	7.1 Visualisation of available slots, slot requests, slot prices, slot allocation and slot use		No		
ACC-REQ-124	For each coordinated airport, and for each coordination interval of each simulated season, the system shall represent in a bar graph all or some of the following simulation outputs upon user selection: - the number of available arrival and departure slots, - the number of slots that would have been requested if the price of all slots were zero, - the price of arrival and departure slots, - the number of allocated arrival and departure slots, - the number of used arrival and departure slots.		Yes	High	
ACC-REQ-124.01	The system implementation shall integrate a library that provides capacity for the creation of bar graphs using the view technology.		Yes	Low	
ACC-REQ-129	For each airline, the system shall represent in a bar graph all or some of the following simulation outputs upon user selection: - the number of slots that the airline would have requested at each coordinated airport if the price of all slots were zero, - the number of slots allocated to the airline, - the number of slots used by the airline.		Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
	7.1.1 Visualisation of auctions economic outcome		No		
ACC-REQ-127	The system shall represent in a line chart the total economic outcome of auctions for each primary allocation of each simulated season		Yes	High	
ACC-REQ-127.01	The system implementation shall integrate a library that provides capacity for the creation of line charts using the view technology.		Yes	Low	
ACC-REQ-128	For each coordinated airport, the system shall represent in a bar chart the total economic outcome of auctions for each primary allocation of each simulated season		Yes	High	
	7.2 Visualisation of performance indicators		No		
	7.2.1 Visualisation of economic efficiency indicators		No		
ACC-REQ-169	The system shall represent in a line chart the total utility obtained by all stakeholders in each season.		Yes	High	
ACC-REQ-170	The system shall represent in a line chart the total utility obtained by airlines in each season.		Yes	High	
ACC-REQ-275	The system shall represent in a line chart the total utility obtained by passengers in each season.		Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
	7.2.2 Visualisation of equity indicators		No		
ACC-REQ-168	The system shall represent in a bar chart the utility obtained by all the airlines included in the scenario.		Yes	High	
ACC-REQ-277	The system shall represent in a bar chart the utility obtained by all the passenger types included in the scenario.		Yes	High	In future evolutions, this may be represented on a map, e.g. showing OD pairs with positive/negative utilities in two different colours
	7.2.3 Visualisation of access and competition indicators		No		
ACC-REQ-288	The system shall represent in a pie chart the distribution of slots owned by airlines at each coordinated airport.		Yes	High	
ACC-REQ-288.01	The system implementation shall integrate a library that provides capacity for the creation of pie charts using the view technology.		Yes	Low	
ACC-REQ-278	The system shall represent in a pie chart the distribution of slots owned by airline alliances at each coordinated airport.		Yes	High	
	7.3 Experiment summary report		No		
ACC-REQ-181	The system may generate a "scenario summary report" with the analysis of each experiment.	Provide a document with a summary of the most important simulation results/indicators. It could be a PDF file, a web page, etc.	Yes	High	
ACC-REQ-181.01	The system shall provide a control to download a file including the report of the simulation.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
	BACK END		No		
	8. General simulation scheme		No		
	The system shall include the following types of agents: *- Airport.* *- Airline.* *- Slot allocation coordinator.* *- Passenger.*		No		
ACC-REQ-089	The sequence of agents' decisions and actions shall follow the scheme included in Annex II General simulation logic.		Yes	High	
ACC-REQ-089.01	The system shall implement a Finite State Machine (FSM) that will execute the referenced diagram.		Yes	Low	
	9. Slot allocation mechanisms		No		
ACC-REQ-065	The system shall simulate the allocation of the series of slots per season consisting of the sequence of all the slots at the same time on the same day of the week during the whole season.	To reduce the complexity of the simulations while still allowing the comparison of slot allocation mechanisms, the requests will represent series of slots including all the slots at the same time on the same day of the week during the whole season (e.g. every Wednesday at 10:00AM during the whole season).	Yes	High	Currently historic rights only apply to slots are allocated in "series", i.e. sequences of at least five slots at the same time on the same day of the week, distributed regularly in the same scheduling season, e.g., a series of 09:15 departure slots over at least five consecutive Mondays (see ACCESS Working Paper #1, Figure 1, p. 14).

Id	Definition	Rationale	IsReq	Level	Comments
	9.1 Primary slot allocation mechanisms				
	9.1.1 Administrative primary slot allocation based on EU Regulation 95/93		No		
	The administrative allocation shall be based on EU Regulation 95/93 and its amendments. However, since many details might not be relevant for the purpose and scope of the project, a number of simplifications shall be applied while keeping the essence of the administrative process (grandfather rights, prioritisation criteria, incumbent and new entrants' categorisation, etc.) so the results are realistic and useful to compare the goodness of alternative allocation mechanisms.		No		
ACC-REQ-007	The administrative allocation shall be performed for a single airport at a time.		Yes	High	
ACC-REQ-007.01	The administrative allocation shall be done sequentially for the list of the airports in the scenario.		Yes	Low	
ACC-REQ-147	The process for the administrative primary slot allocation for the next season shall involve the following steps: 1. Airports communicate their capacity constraints to the slot allocation coordinator. 2. Airlines communicate their requests to the slot allocation coordinator. 2. The coordinator allocates slots to incumbent airlines asking for slots where they have historic rights. 3. The coordinator allocates slots for those re-timing requests of incumbent airlines that do not conflict with the slots allocated so far. The re-timing shall be limited to a maximum number of coordination time intervals TBD. 4. The coordinator allocates 50% of remaining slots from the pool to "new entrant" airlines, upon request. 5. The coordinator allocates the remaining slots to any other airline.		Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-159	Historic rights shall be applied in the following way: - An airline will win/keep historic rights over certain slot series for the next season when the series has been used at least 80% during the last equivalent season. - Airlines using slots below 80% will lose historic rights over them for the next equivalent season.		Yes	High	Only the last equivalent season is considered when applying the 80-20 rule (e.g. for allocating the summer season slots, the operations of series of slots in the last summer season is considered for the 80-20 rule). Airlines with historical rights may make use of it or not. That means that if the airline is interested in keeping a series of slots for which it has grandfather rights for the next equivalent season, it will keep them, but if it is no longer interested in operating that series of slots, it can return them to the pool.
ACC-REQ-159.01	The data repository shall store initialization data for the grandfather rights in pairs (airport, airline).		Yes	Low	
ACC-REQ-143	An airline shall be considered "new entrant" at an airport on a particular day when upon allocation, it would hold fewer than five slots in total on that day.		Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-152	The slot coordinator shall use a random prioritisation criterion to break ties during the allocation process.		Yes	High	
ACC-REQ-152.01	The system shall integrate a library which provides a pseudo-random number generator.		Yes	Low	
ACC-REQ-142	The return of slots to the pool shall accomplish the following criteria: 1. During the season, airlines shall be free to return a slot to the pool any time during the season. 2. At the end of the current season, slots series used below 80% shall return to the pool		Yes	High	
	9.1.2 Primary slot allocation based on optimisation				
	The optimisation mechanisms shall be based on a mathematical programming model that, in a fixed scheduling interval (typically one day), determines the slot allocation that: *- minimises the overall costs of airspace users due to flights (or movements) that cannot be operated due to lack of slots, must be scheduled at times different from the requested ones, and have a duration different from the optimal one;* *- respects the regulations and constraints in terms of: airport capacities, flight durations, aircraft turnaround times;* *- complies with flight durations between the airports (simultaneous allocation).*		No		
ACC-REQ-289	The mathematical formulation in terms of decision variables, objective function and constraints, along with the relevant notation, shall be as specified in Annex III Formulation of the optimisation model.		Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
	9.1.3 Primary slot allocation based on auctions		No		
ACC-REQ-018	The general process for primary slot auctioning shall be the following: 1. Airports communicate their slots constraints to the auctioneer. 2. The auctioneer reads the auction type, the auction configuration parameters, the auction tie-breaking criteria and the auction stop criterion selected by the user. 3. The auctioneer communicates the auction rules to all the participants. The action rules comprise: i) the auction type (i.e. the rules for the iterative auction process, the bidding rules, etc.), ii) the auction tie-breaking criteria and iii) the auction stop criteria. 4. The auctioneer initialises the slot prices according to the option selected by the user. 5. The auctioneer starts the auction process according to the selected mechanism. Successive iterations are conducted according to the auction type selected by the user, until the auction stop criterion is met. 6. The auctioneer checks the feasibility of the slot allocation resulting from the auction, i.e. the compatibility with airports slots constraints. 7. If some of the airport slot constraints are violated, the auctioneer applies the auction tie-breaking (feasibility) mechanism selected by the user. 8. The auctioneer communicates to each airline the slots assigned to that airline and the prices of such slots. 9. The airlines that have received one (or more) slots different from the ones requested in the last round of the auction (as a consequence of the application of the tie-breaking mechanism) communicate to the auctioneer whether or not they accept the new slot allocation. 10. The auctioneer communicates the resulting schedule to the airports.	i) The auctioneer shall know the slots to auction (and the constraints that affect them) at each airport. ii) The configuration of the auction mechanism shall be taken from the configuration chosen by the user. iii) Auctions shall be transparent for all the participants. Auction transparency implies that participants shall know the reason for not getting a slot if they have requested it. Therefore, besides the specification of the iterative auction process, participants shall be aware of the rules to break ties and make solutions feasible. iv) Initial slot prices need to be loaded, whether it is from configuration or from a previous round v) The first request shall be kept to compare it with the final allocation achieved. vi) Once the auction finishes, the resulting allocation may still not comply with slots constraints.	Yes	High	(following the rationale) vii) If slots constraints are violated, it will be necessary to discard or reallocate some requests (the process to make solutions feasible is explained in section 9.1.3.6). viii) After the auction, the auctioneer shall inform the airlines about the final prices of both the slots they got and the ones they didn't get. This way they also know how much each slot has been valued, and they can take this information into account for the next season ix) Airlines that receive a slot different from the ones they requested shall have the right to reject that slot. x) After the auction, the auctioneer shall inform the airports about their schedule so they can know the flight operations they will have in the season

Id	Definition	Rationale	IsReq	Level	Comments
	9.1.3.1 Primary slot allocation based on combinatorial simultaneous ascending auctions		No		
ACC-REQ-048	The auctioneer shall iterate across the following steps: 1. The auctioneer shall communicate the slot prices for the round (arrival + departure) to all the participants. 2. The airlines shall make their slot requests for every airport. 3. The auctioneer shall aggregate, for each airport: 3.1. All the arrival slot requests. 3.2. All the departure slot requests. 3.3. All the slot requests (arrival + departure). 4. The auctioneer shall evaluate the stop criteria: 4.1. The auctioneer shall terminate the auction if the maximum number of rounds has been executed. 4.2. The auctioneer shall terminate the auction if the slot prices/multipliers vary less than the convergence threshold along certain number of consecutive previous rounds (both arrival and departure prices, for every slot). 4.3. The auctioneer shall terminate the auction if the allocation is feasible and the "stop when feasible" criterion has been selected. 5. The auctioneer shall update the slot prices/multipliers for the following round. 5.1. The slot prices for next step shall be calculated as the sum of several multipliers whose value is a function of the degree of compliance of each of the different slots constraints (including rolling constraints). 5.2. The slot prices for next step shall be calculated separately for arrival and departure slots. 5.3. The parameters applied to modify prices/multipliers shall be updated according to the configuration values and the iteration index. 5.4. Each slot constraint violated shall produce a partial price increment proportional to the magnitude of the violation. 6. The auctioneer shall establish the updated prices as the prices for the next round.	Process to be carried out for each iteration of the auction process: i) The auctioneer shall set the initial slot prices starting point for the first round (0 by default) and maybe a minimum acceptable price for each slot can be set (0 by default). ii) The airlines shall know the prices to decide their requests. iii) The auctioneer shall receive all the requests. iv) The capacity is compared with the total demand (arrivals, departures, and their combination), no airline is distinguished. v) Apply the selected stop criteria. vi) If in a coordination time interval the offer of slots is less than demand (arrival/departure) and/or violates any other capacity constraint, the multiplier corresponding to this constraint shall be increased in certain amount for the next step. The value of these variations are modulated by the different parameters (price updating steps: alpha_incr, alpha_decr ...). The value of the multiplier for non-violated constraints must be maintained for the next step.	Yes	High	(following the rationale) vii) The new price slot in a coordination time interval shall be a linear combination of updated multipliers. The final combined effect may increment the prices. viii) Prices can be different for arrival and departure slots. ix) alpha_irnc value can be constant or decrease over the process (i.e. as offer and demand get closer in each slot). x) The price variation takes into account how every capacity constraint is violated. As the auction evolves the slots with lowest demand turns more attractive to airlines than overload slots that are progressively increasing its price. xi) If current demand in a coordination time interval exactly matches all slots constraints, the price of its slots remains for the next round. This could happen when a feasible state of equilibrium is reached. xii) The prices calculated will be effective for the next round, if the auction continues.

Id	Definition	Rationale	IsReq	Level	Comments
	9.1.3.2 Primary slot allocation based on combinatorial simultaneous descending auctions		No		
ACC-REQ-054	The auctioneer shall iterate across the following steps: 1. The auctioneer shall communicate the slot prices for the round (arrival + departure) to all the participants. 2. The airlines shall make their slot requests for every airport. 3. The auctioneer shall aggregate at each airport: 3.1. All the arrival slot requests. 3.2. All the departure slot requests. 3.3. All the slot requests (arrival + departure). 4. The auctioneer shall evaluate the stop criteria: 4.1. The auctioneer shall terminate the auction if the maximum number of rounds has been executed. 4.2. The auctioneer shall terminate the auction if the slot prices vary less than the convergence threshold along certain number of consecutive previous rounds (both arrival and departure prices, for every slot). 4.3. The auctioneer shall terminate the auction if the allocation is feasible and the "stop when feasible" criteria has been selected. 5. The auctioneer shall decrement the price of every slot for the following round. 5.1. The slot price variation shall be calculated as the current price minus a weighted combination of several decrements due to the capacity constraints met (including rolling constraints). 5.2. The slot price variation shall be calculated separately for arrival and departure slots. 5.3. The parameters applied to modify prices shall be updated according to the configuration values and the iteration index. 5.4. Each capacity constraint fulfilled shall produce a partial price decrement proportional to the degree of fulfilment (difference between demand and offer). 6. The auctioneer shall establish the updated prices as the prices for the next round.	Process to be carried out for each iteration of the auction process: i) The auctioneer shall set the initial slot prices for the first round (in any case high enough) and maybe a minimum acceptable price for each slot can be set (0 by default). ii) The airlines shall know the prices to decide their requests. iii) The auctioneer shall receive all the requests. iv) The capacity is compared with the total demand (arrivals, departures, and their combination), no airline is distinguished. v) Apply the selected stop criteria. vi) If in a coordination time interval the offer of slots is greater than demand (arrival/departure) and/or other capacity constraints are satisfied, the price for their slots will be decreased in certain amount for the next round.	Yes	High	(following the rational) vii) The new price slot in a coordination time interval shall be the current price (arrival/departure) minus certain decrement. viii) Prices can be different for arrival and departure slots. ix) alpha_decr value can be constant or decrease over the process (i.e. as offer and demand get closer). x) The price variation takes into account how every capacity constraint is satisfied. xi) If current demand in a coordination time interval meets and/or violates each of the slots constraints, the price of its slots remains for the next round and this makes these overload slots each time less attractive to airlines than available slots that are progressively reducing its price. xii) The prices calculated will be effective for the next round, if the auction continues.

Id	Definition	Rationale	IsReq	Level	Comments
	9.1.3.3 Primary slot allocation based on a Combinatorial Auction using a Walrasian regular Tâtonnement (adaptive and non-adaptive) price update scheme		No		
ACC-REQ-185	The auctioneer shall iterate across the following steps: 1. The auctioneer shall communicate the slot prices for the round (arrival + departure) to all the participants. 2. The airlines shall make their slot requests for every airport. 3. The auctioneer shall aggregate at each airport: 3.1. All the arrival slot requests. 3.2. All the departure slot requests. 3.3. All the slot requests (arrival + departure). 4. Evaluate the stop criterion. The auctioneer shall terminate the auction if the selected stop criteria is met. 5. The auctioneer shall update the price of every slot by certain amount (increment/decrement) for the following round. 5.1. The slot price variation shall be calculated as the current price plus a weighted combination of several increments/decrements due to the slots constraints violations/compliances (including rolling constraints). 5.2. The slot price variation shall be calculated separately for arrival and departure slots. 5.3. The parameters applied to modify prices shall be updated according to the auction type, the configuration values and the iteration index. 5.4. Each slot constraint violated shall produce a partial price increment proportional to the magnitude of the violation. 5.5. Each slot constraint fulfilled shall produce a partial price decrement proportional to the magnitude of the fulfilment. 6. The auctioneer shall establish the updated prices as the prices for the next round.	Process to be carried out for each iteration of the auction process: i) The auctioneer shall set the initial slot prices starting point for the first round and maybe a minimum acceptable price for each slot can be set. ii) The airlines shall know the prices to decide their requests. iii.a) The auctioneer shall receive all the requests. iii.b) The capacity is compared with the total demand (arrivals, departures, and their combination), no airline is distinguished. iv) Apply the selected stop criteria.	Yes	High	(following the rationale) v.b) Prices can be different for arrival and departure slots. v.c) alpha_incr and alpha_decr value shall be recalculated if needed. v.d) The price variation takes into account how every capacity constraint is violated. If current demand in a coordination time interval fulfils and/meets all slots constraints, the price of its slots remains for the next round and this makes these slots each time more attractive to airlines than the overloaded slots that are progressively increasing its price. vi) The prices calculated will be effective for the next round.

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-035	For Walrasian non-adaptive regular Tâtonnement, alpha_incr and alpha_decr values shall be constant over the process.		Yes	High	The values of alpha's have to be correctly selected to allow the convergence to an optimal (equilibrium) slot allocation.
ACC-REQ-044	For Walrasian adaptive regular Tâtonnement, alpha_incr and alpha_decr values shall be decreased over the process following a gradient function.	The auctioneer will make aggressive price updates in early iterations of the auction to force a quick alignment of demand with the offer. The values of alphas are decreased in later iterations to fine tune the quality of the slots allocation.	Yes	High	
	9.1.3.4 Feasibility of auction results		No		
	In case the auction is stopped before all the capacity constraints are fulfilled, this process will be applied to obtain a "feasible" allocation that matches all the capacity constraints. *The mathematical specification of the feasibility mechanism is detailed in Annex V Auctions feasibility mechanism.*		No		
ACC-REQ-211	The feasibility mechanism shall produce slot allocations that do not violate any slots constraint.	This is the aim of applying a feasibility mechanism to post-process the results of an auction.	Yes	High	A slot allocation will be considered as "feasible" when it fulfils all airports' slots constraints and could actually work without any modification.

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-212	The feasibility mechanism shall take as input the slot allocation produced by the auction.	This mechanism uses the auction result as baseline.	Yes	High	
ACC-REQ-213	The feasibility mechanism shall only modify the auction slot allocation if any slots constraint is violated.	Solve a situation where several airlines are tied after the auction and there is not enough capacity for all of them; or a situation where the auction has been stopped before equilibrium and the allocation produced still violates some capacity constraint.	Yes	High	
ACC-REQ-216	The feasibility mechanism shall follow the following steps: 1. Identification of the slot requests that violate any airport slots constraint. 2. Prioritisation of slot requests according to the selected criteria. 3. The least prioritised slot request shall be progressively displaced, one coordination interval at a time, until it does not violate any capacity constraint. 4. If any airport slots constraint is still violated, the following slot request in the prioritisation shall be displaced.	The feasibility mechanism will try to produce an allocation as similar as possible to the auction result.	Yes	High	
ACC-REQ-214	The criteria "descending total price of request (arrivals + departures)" shall prioritise those slot requests included in a more expensive combination (higher total economic amount).	"Cheaper" requests would be displaced before (sum of the prices of all the slots in the request).	Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-291	The criteria "descending number of total slots" shall prioritise those slot requests containing higher number of slots.	Combinatorial requests asking for a higher number of slots are prioritised.	Yes	High	
ACC-REQ-215	The "random prioritisation" shall prioritise slot requests randomly.	A random criteria shall always be present to be able to break ties in any case.	Yes	High	
	9.1.4 Hybrid primary allocation		No		
	This section specifies hybrid mechanisms for primary allocation, explaining how to combine some of the mechanisms already specified in other sections. *This mechanism:* *- allocates part of the capacity according to the administrative process,* *- allocates the remaining slot requests through optimisation or auctions*		No		
ACC-REQ-058	A percentage TBD of the available slots shall be allocated following the rules of the administrative allocation process.		Yes	High	
ACC-REQ-059	The remaining slots in the pool shall be allocated according to one of the optimisation or auction mechanisms specified.		Yes	High	The optimisation or auction mechanism works in the same way. The only difference is that the initially available slots have to be calculated.

Id	Definition	Rationale	IsReq	Level	Comments
	9.2 Secondary slot allocation mechanisms		No		
	The secondary allocation shall be based on several types of markets where the airlines will be allowed to exchange, sell or acquire certain slots. These slots may comprise both slot already allocated in the primary allocation and unallocated slots that remain in the pool. *The secondary allocation mechanisms will be structured as:* *- Decentralised market with monetary exchanges.* *- Decentralised market with non-monetary exchanges.* *- Centralised market with monetary exchanges.* *The optimum design of a secondary market depends on how well the primary allocation worked, and the dynamicity of the environment.*		No		
ACC-REQ-095	The unallocated slots in the pool shall be available to be requested by airlines in the secondary market.	Allow free slots to be acquired in the secondary market.	Yes	High	
ACC-REQ-270	There shall be a pre-established economic fare to be applied to the exchange.	Prevent airlines from using the secondary market as a speculative market, e.g. 2% of the slot price	Yes	High	This can be set to zero in some cases.
ACC-REQ-271	The exchange fare associated to a slot shall be paid half by the seller and half by the buyer	Fares are shared by buyers and sellers, since both benefit from the trade	Yes	High	
ACC-REQ-272	There shall be a central panel with public information	To publish some information that needs to be shared between market participants	Yes	High	
ACC-REQ-272.01	The data repository shall implement the blackboard pattern to allow interaction between agents without replication of the data.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
	9.2.1 Centralised secondary market with monetary exchanges		No		
	The secondary allocation with centralised market shall allow periodic time windows where some slots will be auctioned again, involving airlines willing to sell some of their allocated slots as well as the slots in the pool. The process is centralised because it involves the figure of a coordinator/auctioneer: the slots offered are published in a "panel", and every airline is allowed to bid for them in a combinatorial Walrasian auction carried out by the auctioneer. *This secondary market carries a process similar to a primary allocation with a combinatorial Walrasian auction, with two differences:* *- Only part of the capacity is offered (some of the already allocated slots plus the unallocated ones).* *- The economic result for each company depends on the new prices of the slots sold minus the prices of the slots acquired.*		No		
ACC-REQ-099	The secondary allocation with centralised market shall take place periodically with a pre-defined frequency		Yes	High	
ACC-REQ-100	The central panel shall be used according to the following rules: - Airlines shall publish in the central panel all the slots they are willing to sell. - The unallocated slots in the pool shall be published in the central panel.	Publish some information that needs to be shared between market participants	Yes	High	There shall be a criteria which allows the airline agent to identify the slots that he is willing to sell.
ACC-REQ-100.01	The data model of the slots shall contain a flag indicating that the slot are available to sell.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-117	Airlines shall also communicate to the auctioneer the minimum price they will accept to sell each slot that they announce in the central panel.	The auctioneer shall know these minimum prices to be able to vary the "offer" according to the current prices. These minimum prices shall remain private and not be disclosed to other airlines.	Yes	High	Example: 2 slots with minimum prices of 10 and 15. If the price gets lower than 15, the auctioneer has to internally remove one of the slots from the offer, and recalculate the prices again. This might lead to oscillations around one of these prices, and could impact the convergence, but the feasibility mechanism should solve this issue.
ACC-REQ-117.01	The data model of the slots shall contain a field indicating the minimum price that seller airline can accept.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-101	The auctioneer shall execute a combinatorial Walrasian auction following the same process specified for the primary allocation: - The initial slot prices for the secondary auction shall be the prices of the previous auction. - The coordinator shall limit the minimum prices acceptable for those slots already assigned in previous allocations. The minimum price of a slot shall be a percentage TBD of its price in the previous auction. - Airlines shall request (bid) their preferred slots depending on the prices from the ones available in the central panel during the auction process. - Airlines shall not bid for the same slots they are trying to sell in the auction. - The auctioneer shall execute the feasibility mechanism when the auction ends. - When the auction ends, the airline that wins shall take it and pay the new price established.		Yes	High	
ACC-REQ-102	At the end of the process each airline shall pay: - the sum of the prices of the slots it acquires, - minus the sum of the prices of the slots it sells, - plus the corresponding fares associated to those exchanges.		Yes	High	The overall amount can be positive (the airline pays money) or negative (the airline receives money), depending on the situation.
ACC-REQ-136	At the end of the process the auctioneer communicates: - the final allocations to each airline, - the final allocations at each airport, - the final slot prices to airlines and airports.		Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
	9.2.2 Decentralised secondary market		No		
	The decentralised secondary market with monetary exchanges is a continuous asynchronous market where airlines bargain for certain slots without being coordinated by any central actor. Only a public panel will show up to date offers and request of the airlines, so they know who they can negotiate with. The airlines are responsible for making agreements that shall be informed to the coordinator.		No		
ACC-REQ-257	The decentralised secondary market shall be a continuous market, open all along the season.		Yes	High	
ACC-REQ-258	The central panel shall be used according to the following rules: - Airlines shall publish freely the slots they are willing to trade (slot offers) at any moment. - Airlines shall publish freely the slots they are willing to acquire (slot requests) at any moment.		Yes	High	
ACC-REQ-259	The negotiation for the exchanges shall follow the following rules: - Airlines shall start a negotiation process with any other airline present in the central panel at any moment. - Each airline shall bargain with one or many airlines at the same time. - The bargaining process between airlines shall be carried out privately. - If there is an agreement to trade after the bargaining, both airlines shall inform about it to the coordinator.		Yes	High	
ACC-REQ-260	Airlines shall agree to exchange slots on the following basis: - one for one, - one for many, - many for one, - many for many.		Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-261	When a deal is closed, each airline shall pay the corresponding economic amounts associated to the exchanges, if any.		Yes	High	
ACC-REQ-262	After a trade, the coordinator shall update: - the slot allocation of each airline, - the slot allocation at each airport.		Yes	High	
	9.2.2.1 Decentralised secondary market with monetary exchanges		No		
	The slot prices of the last auction apply, therefore the economic amounts transferred between airlines are result of the price difference between the slots exchanged.		No		
ACC-REQ-263	Only monetary exchanges based on the economic value of the slots shall be allowed.		Yes	High	
ACC-REQ-264	The economic value applying to each slot shall be its price in the last auction.		Yes	High	
ACC-REQ-265	The agreements established between airlines to exchange slots shall be either: - Exchange of certain slot/s for an economic amount. - Exchange of certain slot/s for slot/s plus an economic amount.		Yes	High	
ACC-REQ-266	When a deal is closed, each airline shall pay the sum of these economic amounts: - The sum of prices of the slots it acquires minus the prices of the slots sold. - The fares associated to the trades performed.		Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
	9.2.2.2 Decentralised secondary market with non-monetary exchanges		No		
	No monetary exchanges are allowed, so airlines will agree to exchange slots only when they both evaluate the exchange as positive for themselves (both of them optimise their objective functions).		No		
ACC-REQ-267	Only non-monetary exchange between airlines that agree to trade slots shall be allowed.		Yes	High	
ACC-REQ-268	The agreements established between airlines to exchange slots shall be: - Exchange of certain slot/s for certain slot/s.		Yes	High	Airlines will only agree to trade slots when both improve their situation with the exchange (win-win).
ACC-REQ-269	When a deal is closed, each airline shall only pay the fares associated to the trades performed.	Although the slot exchange is not associated to a monetary compensation, administrative fares may apply	Yes	High	
	10. Agent definition and behavioural models		No		
ACC-REQ-008	The system shall include an 'airport' agent model.	Allow the integration of airports into the simulation.	Yes	High	
ACC-REQ-008.01	The system implementation shall contain one interface defining the behaviours of the airport agent.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-075	The system shall include an 'airline' agent model.	Allow the integration of airlines into the simulation.	Yes	High	
ACC-REQ-075.01	The system implementation shall contain one interface defining the behaviours of the airline agent.		Yes	Low	
ACC-REQ-076	The system shall include a 'slot allocation coordinator' agent model.	Implement the selected slot allocation mechanisms.	Yes	High	
ACC-REQ-076.01	The system implementation shall contain one interface defining the behaviours of the slot allocation coordinator agent.		Yes	Low	
ACC-REQ-196	The system shall include a 'passenger' agent model.	Simulate passengers' choices once the airlines offer their schedules and fares.	Yes	High	
ACC-REQ-196.01	The system implementation shall contain one interface defining the behaviours of the passenger agent.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
	10.1 Airport agents		No		
	10.1.1 Airport attributes		No		
	Airport agents shall have the following attributes: *1. Airport identifier, following ICAO 4-letter code.* *2. Position, defined as a pair (latitude, longitude).* *3. Airport type: Primary (Hub) / Secondary (Regional).* *4. Airport level: Non-coordinated (Level 1) / Schedules facilitated (Level 2) / Coordinated (Level 3).* *5. Coordination time interval, defined in minutes.* *6. Landing fee profile.* *7. Opening/closing hours.* *8. Arrival capacity profile, defined in number of arrival slots per coordination time interval along the day.* *9. Departure capacity profile, defined in number of departure slots per coordination time interval along the day.* *10. Infrastructure capacity profile, defined in number of infrastructure slots per coordination time interval along the day.* *11. Rolling capacity time interval, defined as an integer number of coordination time intervals.* *12. Rolling arrival capacity profile, defined in number of slots per rolling capacity time interval along the day.* *13. Rolling departure capacity profile, defined in number of slots per rolling capacity time interval along the day.* *14. Rolling infrastructure capacity profile, defined in number of slots per rolling capacity time interval along the day.* *15. Possibility of capacity expansion: Yes / No.* *16. Possibility of landing fees modification: Yes / No.*		No		

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-139	Airport agents shall have an attribute called "Airport Identifier" consisting of a 4-letter code.		Yes	High	
ACC-REQ-140	Airport agents shall have an attribute called "Position" consisting of a pair (latitude, longitude).		Yes	High	
ACC-REQ-141	Airport agents shall have an attribute called "Airport Type" taking one of the following values: "Primary" or "Secondary".		Yes	High	
ACC-REQ-186	Airport agents shall have an attribute called "Landing Fee Profile" consisting of a value in euros per coordination time interval along the day.		Yes	High	Landings fees can be different for different coordination time intervals.
ACC-REQ-234	Airport agents shall have an attribute called "Opening Hours" consisting of the initial and last time of the day on which operations are permitted.	Real constraints for both coordinated and non-coordinated airports.	Yes	High	
ACC-REQ-146	Airport agents shall have an attribute called "Airport Level" taking one of the following values: "Non-coordinated", "Schedules facilitated" or "Coordinated".		Yes	High	
ACC-REQ-148	Airport agents for which the "Airport Level" attribute is set to "Coordinated" shall have an attribute called "Coordination Time Interval" that shall take one of the following values: 5, 10, 15 or 20 minutes.		Yes	High	
ACC-REQ-150	Airport agents for which the "Airport Level" attribute is set to "Coordinated" shall have an attribute called "Arrival Capacity Profile" consisting of a number of arrival slots per coordination time interval along the day.		Yes	High	Capacity declaration profile may vary throughout the day (see ACCESS Working Paper #1). The capacity profile shall incorporate this variation, night curfews, etc.

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-151	Airport agents for which the "Airport Level" attribute is set to "Coordinated" shall have an attribute called "Departure Capacity Profile" consisting of a number of departure slots per coordination time interval along the day.		Yes	High	Capacity declaration profile may vary throughout the day (see ACCESS Working Paper #1). The capacity profile shall incorporate this variation, night curfews, etc.
ACC-REQ-156	Airport agents for which the "Airport Level" attribute is set to "Coordinated" shall have an attribute called "Infrastructure Capacity Profile" consisting of a number of infrastructure slots per coordination time interval along the day.	Account for capacity limitations other than runway capacity. The (number of aircraft waiting to take-off + the number of arrivals - the number of departures) shall not exceed "infrastructure capacity".	Yes	High	If this makes the price update algorithm too complicated, we may simply take it into account in the feasibility check.
ACC-REQ-153	Airport agents for which the "Airport Level" attribute is set to "Coordinated" shall have an attribute called "Rolling Capacity Time Interval" consisting of an integer number of coordination time intervals.		Yes	High	
ACC-REQ-154	Airport agents for which the "Airport Level" attribute is set to "Coordinated" shall have an attribute called "Rolling Arrival Capacity Profile" consisting of a number of arrival slots per rolling capacity time interval along the day.		Yes	High	
ACC-REQ-190	Airport agents for which the "Airport Level" attribute is set to "Coordinated" shall have an attribute called "Rolling Departure Capacity Profile" consisting of a number of departure slots per rolling capacity time interval along the day.		Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-191	Airport agents for which the "Airport Level" attribute is set to "Coordinated" shall have an attribute called "Rolling Infrastructure Capacity Profile" consisting of a number of infrastructure slots per rolling capacity time interval along the day.		Yes	High	
ACC-REQ-155	Airport agents shall have an attribute called "Possibility of Capacity Expansion" taking one of the following values: "Yes" or "No".	Capacity expansion may not be possible at all airports due to different types of restrictions (land use availability, environmental restrictions, etc.).	Yes	High	
ACC-REQ-236	Airport agents shall have an attribute called "Possibility of Landing Fees Modification" taking one of the following values: "Yes" or "No".		Yes	High	
	10.1.2 Initialisation of airport agents		No		
ACC-REQ-019	At the beginning of each simulation, an airport agent shall be created for each of the airports selected by the user during the scenario definition.		Yes	High	
ACC-REQ-160	The attributes of the airport agents shall be initialised to those attributes defined in the airport data repository for the airports selected by the user during the scenario definition.		Yes	High	
ACC-REQ-178	If during the scenario definition the user has selected the option that airports may not vary their capacity, the attribute "Possibility of Capacity Expansion" of all the airport agents shall be set to "No".	Allow the user not to simulate this possibility	Yes	High	
ACC-REQ-221	If during the scenario definition the user has selected the option that airports may not modify landing fees, the attribute "Possibility of Landing Fees Modification" of all the airport agents shall be set to "No".	Allow the user not to simulate this possibility	Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
	10.1.3 Airport behavioural model		No		
	At the beginning of each season, airport agents shall make the following decisions: *- Communicate capacity and landing fees.* *- They may expand capacity, if they have the possibility to do this and this option is enabled in the configuration of the scenario.* *At each simulation step, airport agents shall make the following decisions/take the following actions:* *- Calculate and store slot utilisation.*		No		
ACC-REQ-053	Before each pre-season primary allocation, if the attribute "Possibility of Capacity Expansion" is "Yes", airports shall update their attributes according to the following algorithm: IF ("No of used slots at step i-1" > 90% of "Available slots" at step i-1) AND ("No of used slots at step i-2" > 90% of "Available slots" at step i-2) AND ("Forecast Demand" at i+1 > "Actual Demand" at i) AND ("Forecast Demand" at i+2 > "Forecast Demand" at i+1) THEN CAPACITY = CAPACITY * TBD	Allow the simulation of capacity expansions.	Yes	High	Capacity increase factor to be determined
ACC-REQ-195	Before each pre-season primary allocation, if the attribute "Possibility of Landing Fees Modification" is "Yes", airports shall update their "Landing Fees Profile" attribute according to the following algorithm: LandingFees = LandingFees (1 + Capacity_Expansion%) i.e. the increase in Landing fees will be proportional to the capacity expansion decided, in order to cover the investment	Simulate the interactions between landing fees modification and changes in slot demand.	Yes	High	For the first version of the model this takes a simple rule that increasing capacity by x% will increase landing fees by x%, just reflecting the financing of capacity expansion.

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-295	At each simulation step, airport agents shall update slot utilisation.	Monitor slot use for assessment of efficiency, application of grandfather rights, etc.	Yes	High	
	10.2 Airline agents		No		
	10.2.1 Airline attributes		No		
	Airline agents shall have the following attributes: *1. Airline identifier following ICAO 3-letter code.* *2. Airline business model.* *3. Hub.* *4. Fleet composition.* *5. Operational costs factors.* *6. Desired schedule.* *7. Desired fares (for the Desired Schedule).* *8. Expected profit (for the Desired Schedule).* *9. Actual schedule.* *10. Actual fares.* *11. Actual profit (as a result of operation of the Actual Schedule).* *12. Alliance.* *13. Possibility of fleet modification: Yes / No.*		No		
ACC-REQ-187	Airline agents shall have an attribute called "Airline Identifier" consisting of a 3-letter code.		Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-223	Airline agents shall have an attribute called "Airline Business Model" taking one of the following values: "Network", "Low Cost", "Regional", "Charter" or "Cargo".	Allow: - the definition of certain behavioural rules depending on the business model, since the characteristics of the business model may potentially affect some bidding rules for the slot assignment (e.g. network carriers is only interested in starting or ending flight in its main hub) - the analysis of the impact of different slot allocation mechanisms on different types of airlines, e.g. filtering certain results per airline type, etc. The four airline types identified as the most relevant for the slot allocation problem are Network, Low Cost, Regional and Charter (see ACCESS Working Paper #3). For more complicated scenarios it may also be useful to add Cargo, as there also some daytime cargo operations.	Yes	High	In a first step we will focus on network, regional and low cost airlines.

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-224	Airline agents shall have an attribute called "Hubs" consisting of the identifier of the airport(s) where the airline has its hub(s) or the identifier XXX if the airline does not have a hub.	The bidding logic can change for an airline if bidding for slots at the Hub airport	Yes	High	
ACC-REQ-225	Airline agents shall have an attribute called "Fleet Composition" consisting of: - a set of aircraft types from those included in the aircraft data repository; and - the number of each aircraft type that the airline possesses.	The fleet composition will limit the total amount of slots that the airline can serve in one season. If the slots requested cannot be served with the fleet associated to that airline, the airline may want to increase its fleet.	Yes	High	
	Airline operational cost for each flight shall be calculated according to the following expression: *BHDOC + IOC + Landing fees, with:* *BHDOC = f (average_BHDOC, fuel price)* *IOC = a x BHDOC*		No		
ACC-REQ-226	Airline agents shall have an attribute called "Operational Costs Factors" for each flight in their fleet, consisting of: - Average Block Hour Direct Operating Cost (BHDOC) tabulated by aircraft type. - Average Indirect Operating Cost expressed as a percentage over the Average BHDOC for different aircraft types.		Yes	High	Typical values can be found in University of Westminster's reports from 2004 and 2011.

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-198	Airline agents shall have an attribute called "Desired Schedule", consisting of the list of all flights that maximise the airline's Expected Profit, including: - origin airport (ICAO 4-letter code), - destination airport (ICAO 4-letter code), - aircraft type designator (ICAO 3 or 4-characters code), - scheduled time of departure, - scheduled time of arrival, - expected flight operational cost.		Yes	High	These are the flights that the airline would like to offer
ACC-REQ-200	Airline agents shall have an attribute called "Expected Profit" consisting of the profit expected for each of the flights included in the "Desired Schedule".		Yes	High	This is the profit that the airline expects to realise for the flights that it would like to offer.
ACC-REQ-199	Airline agents shall have an attribute called "Fares", consisting of: - the set of fares (in euros) offered by the airline, - the number of seats offered per fare, for each of the flights included in the Actual Schedule.		Yes	High	For example, there can be two different fares, one for Business and one for Economy.
ACC-REQ-188	Airline agents shall have an attribute called "Actual Schedule", consisting of the list of all flights offered by the airline, including: - origin airport (ICAO 4-letter code), - destination airport (ICAO 4-letter code), - aircraft type designator (ICAO 3 or 4-characters code), - scheduled time of departure, - scheduled time of arrival, - actual flight operational cost.		Yes	High	This is the actual schedule that the airline will operate, once it has acquired the necessary slots.
ACC-REQ-205	Airline agents shall have an attribute called "Actual Profit" consisting of the profit realised for each of the flights included in the "Actual Schedule".		Yes	High	This is the actual profit that the airline realises for the flights offered as a result of the actual behaviour of demand.

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-189	Airline agents shall have an attribute called "Alliance" consisting of a one character code.	Allow the representation of alliances. This could be especially useful in the secondary market, as it may influence airlines' behaviour (e.g., collusion).	Yes	High	
ACC-REQ-207	Airline agents shall have an attribute called "Possibility of Fleet Modification" taking one of the following values: "Yes" or "No".		Yes	High	
	10.2.2 Initialisation of airline agents		No		
ACC-REQ-183	At the beginning of each simulation, an airline agent shall be created for each of the airlines selected by the user during the scenario definition.		Yes	High	
ACC-REQ-184	The attributes of the airline agents shall be initialised to those attributes defined in the airline data repository for the airlines selected by the user during the scenario definition.		Yes	High	
ACC-REQ-220	If during the scenario definition the user has selected the option that airlines may not modify their fleet, the attribute "Possibility of Fleet Modification" of all the airline agents shall be set to "No".		Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
	10.2.3 Airline behavioural model		No		
	At each simulation step, airline agents shall make the following decisions / take the following actions: *1. Calculation of "Desired Schedule", i.e. set of routes that airline would like to fly, aircraft types on these routes, flight frequencies and departure times. For iterative processes (e.g. auctions), the "Desired Schedule" shall be calculated at each iteration.* *2. Definition of "Desired Fares" for the "Desired Schedule". For iterative processes (e.g. auctions), the "Desired Fares" shall be calculated at each iteration.* *3. Calculation of "Expected Profit". For iterative processes (e.g. auctions), the "Expected Profit" shall be calculated at each iteration.* *4. Decide which slots they will request and at what maximum price. For iterative processes (e.g. auctions), this shall be calculated at each iteration.* *5. Decide which slots they will offer and at what minimum price. For iterative processes (e.g. auctions), this shall be calculated at each iteration.* *6. Pay for the slots they get as a result of the slot allocation process.* *7. Be paid for the slots they sell in the secondary market.* *8. Publish "Actual Schedule" and "Actual Fares".* *9. Calculate "Actual Profit".* *10. Decide whether to expand and/or renew their fleet.*		No		

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-057	At each simulation step and for each iteration of the slot allocation process, airline agents shall update their "Desired Schedule", by: maximize(Expected Profit) subject to: - Availability of slots and their cost. - Availability of aircraft in the fleet and the related Expected Flight Operational Cost. - Connectivity constraints for origin and destination airport. - Feasible turnaround time between consecutive flights operated by the same aircraft. - Expected Load Factor for Fare i, depending on the OD pair, time of the departure and competition level on the same route.	The "Desired Schedule" is the one that maximises the "Expected Profit" for a given set of values of: - Demand Forecast - Fuel Price Forecast - Slot Prices	Yes	High	Refer to Babic and Kalic for a heuristic algorithm for create new flight schedule. The computational complexity of this problem could easily be prohibitive even for small problem instances. The complexity and possible assumptions/limitations to make the problem tractable need to be investigated.
ACC-REQ-255	At each simulation step, Airline agents shall calculate the Initial Fare i for passenger in Class i as the Utility Curve plus or minus a random % deviation depending on the type of Airline.	The random deviation could be dependent on the Airline type (e.g. lowcost -5%, Network +10%) and in order to introduce some variability in Fares.	Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-060	At each simulation step and for each iteration of the slot allocation process, airline agents shall update the "Desired Fares" for their "Desired Schedule" according to the following procedure: The airfare is indirectly controlled as a rate of change of Fare i (Δ TP) by the flight load factor and competition level (CL) of the current market situation: Rule 1: If Load Factor is High, and CL is High, then Δ TP is Negligible. Rule 2: If Load Factor is High, and CL is Medium, then Δ TP is Small Positive. Rule 3: If Load Factor is High, and CL is Low, then Δ TP is Positive. Rule 4: If Load Factor is Medium, and CL is High, then Δ TP is Small Negative. Rule 5: If Load Factor is Medium, and CL is Medium, then Δ TP is Negligible. Rule 6: If Load Factor is Medium, and CL is Low, then Δ TP is Small Positive. Rule 7: If Load Factor is Low, and CL is High, then Δ TP is Negative. Rule 8: If Load Factor is Low, and CL is Medium, then Δ TP is Negligible. Rule 9: If Load Factor is Low, and CL is Low, then Δ TP is Negligible.	Fuzzy update as proposed in Kim, Teodorovic and Trani (2005).	Yes	High	Another approach can be (Akartunali et al. 2013): For each of the flights included in the "Desired Schedule": - Determine the number of different Fare classes, based on the input scenario parameter. - Determine a standardised fare profile f(t), which describe the fare variation by time of day, irrespective of OD pair. - Determine the scale factor alpha_od, based on industry standard values of unit fixed cost per flight and minimum flight time between O and D. - Partition the market demand for each OD pair.
ACC-REQ-061	At each simulation step and for each iteration of the slot allocation process, airline agents shall update their "Expected Profit" according to the following algorithm: For each of the flights included in the "Desired Schedule": Expected Profit = Sum (Expected Number of Passenger in Class i x Fare i) - Expected Flight Operational Cost - Slot Price		Yes	High	During an auction, the slot price to be used is the one set by the auctioneer for that particular iteration.

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-201	At each simulation step and for each iteration of the slot allocation process, airlines shall request the slots required for their "Desired Schedule".	Airlines will not bid for a slot if they do not expect an economic profit from it.	Yes	High	This is applicable to both primary and secondary allocation, subject to the rules of each particular mechanism.
ACC-REQ-210	When making combinatorial requests, airlines may keep the same number of slots requested in each request, varying only the coordination intervals where they are requested.	Performing a whole evaluation of every possible slot for each round in a combinatorial auction may require a very high number of calculations to be performed per airline. When several airports and lots of slots are involved in the auction, the number of combinations increases by several orders of magnitude. Splitting the total slot requests in smaller combinations of the flights which are really interrelated, and only varying them to displace the requested slots to certain coordination time intervals, may help reduce the computational complexity.	Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-038	When the auctioneer is performing the feasibility mechanism, airlines shall accept or reject certain slot allocation they are proposed by the auctioneer.	Airlines shall accept the proposed allocation if it is equal to their request, but they could reject it if is different (because an allocation in different coordination intervals would imply different utility and different costs).	Yes	High	
ACC-REQ-217	At each simulation step and for each iteration of the secondary slot allocation process, airlines shall offer the slots that they possess and that are not required for their "Desired Schedule".		Yes	High	This is only applicable to the secondary market, where airlines can buy or sell slots.
ACC-REQ-071	If an airline belongs to an alliance, in a decentralised secondary market it shall bargain and agree slot exchanges only with other airlines belonging to the same alliance.	Allow different airline behaviours when alliances exist and simulate imperfect markets.	Yes	High	The simplest strategy when alliances are considered would be only to bargain/agree slot exchanges with other airlines belonging to the same alliance, and not negotiating with independent airlines or with those belonging to different alliances.

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-206	At each simulation step, airlines shall pay for all the slots they have been allocated	Airlines may have over-demanded some slots as a strategy (jump bidding), but it is compulsory that they pay for all of them according to the auction / secondary market prices. After the allocation, they will be free to trade them in the secondary market.	Yes	High	
ACC-REQ-294	At each simulation step, airlines shall be paid for the slots they have sold.		Yes	High	
ACC-REQ-218	At each simulation step, airlines shall update the "Actual Schedule" by making it equal to that communicated to the airline by the auctioneer at the end of the slot allocation process.		Yes	High	
ACC-REQ-219	At each simulation step, airlines shall publish their "Actual Schedule" and their "Actual Fares"		Yes	High	
ACC-REQ-062	At the end of each simulation step, airline agents shall calculate their "Actual Profit" according to the following formula: For each of the flights included in the "Actual Schedule": Actual Profit = Sum (Actual Number of Passengers in Class i x Actual Fare i) - Actual Flight Operational Cost - Slot Price		Yes	High	This is the actual profit that the airline realises for the flights offered as a result of the actual behaviour of demand

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-235	At each simulation step, if the attribute "Possibility of Fleet Modification" is "Yes", airline shall update their "Fleet" attribute according to the following algorithm: If (for some OD and for some number TBD of past simulation steps) [(Expected profit) * (1+ profit_increase)^(pay_off_period)>Aircraft_Price_i] AND [slots available at O and D] then purchase Aircraft type i with profit_increase indicating the expected increase in profit from year to year, pay_off_period the number of years to payback the investment for aircraft purchase and Aircraft_Cost_i the price to purchase Aircraft of type i (offering passenger capacity relative to type i Aircraft). profit_increase, pay_off_period and Aircraft_Price_i are parameters defined in the Scenario under simulation.	Allow expanding fleet according to new potential demand to be satisfied by an Airline to reflect expanding markets. It could be interesting in the future to consider the case in which Airlines can reduce their fleet due to losing slots at some airports or economic downturn.	Yes	High	
	10.3 Slot allocation coordinator agent		No		
	At each simulation step an allocation takes place, the slot allocation coordinator, shall accomplish the following actions, which are detailed in the specific allocation mechanism selected.		No		
ACC-REQ-285	During administrative slot allocation, the slot allocation coordinator shall: - announce the available slots - gather the airlines' requests - allocate slots according to the administrative rules - announce the final slot allocation		Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-021	The slot coordinator, acting as auctioneer both in a - primary allocation by means of auctions, - secondary centralised market with monetary exchanges, shall perform the following actions at each simulation step: - announce the available slots - gather the airlines' requests - update slot prices - when the auction is finished, execute the feasibility mechanism - announce the final slot allocation and the final prices	The actions carried out by the coordinator follow the same scheme in primary auctions and a centralised secondary market	Yes	High	
ACC-REQ-137	In a decentralised secondary market, at each simulation step, the slot allocation coordinator upon notification of an agreement between airlines to trade slots, shall update and announce the new slot allocation	In a decentralised secondary market, the coordinator only monitors the transfers and announces the changes in the allocation	Yes	High	
	10.4 Passenger agent		No		
	Each passenger will represent a group of passengers in real life that correspond to the total demand between a certain origin-destination				
	10.4.1 Passenger attributes		No		
	Passenger agents shall have the following attributes: *1. Passenger group identifier.* *2. Airport of origin.* *3. Airport of destination.* *4. Class: Business / Leisure.* *5. Number of passengers.* *6. Utility curve.* *7. Value of time.*				

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-157	Passenger agents shall have an attribute called "Passenger Identifier".		Yes	High	
ACC-REQ-250	Passenger agents shall have an attribute called "Airport of origin".		Yes	High	
ACC-REQ-233	Passenger agents shall have an attribute called "Airport of destination".		Yes	High	
ACC-REQ-251	Passenger agents shall have an attribute called "Class" consisting of a two digits code equivalent to the class to which the passenger belong.	For example business and leisure passengers	Yes	High	
ACC-REQ-253	Passenger agents shall have an attribute called "Utility curve" in euros.		Yes	High	As a first approach, we will consider a generic utility curve for all business (leisure) passengers regardless of the OD pair Here the model by Akartunali (2013) can provide useful inputs. Values for schedule displacement costs have been provided by Adler (2005): Business 30,3+-22,9 US$/min and Leisure 4,8+-5,7US$/min.

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-252	Passenger agents shall have an attribute called "Value of time" in euro per minute	For instance	Yes	High	As a first approach, we will consider a generic value of time for all business (leisure) passengers regardless of the OD pair
	10.4.2 Initialisation of passenger agents		No		
ACC-REQ-296	At the beginning of each simulation, a passenger agent shall be created for each origin-destination pair and passenger type included in the scenario definition.			High	
ACC-REQ-297	The attributes of "Number of passengers", "Utility curve" and "Value of time" shall be set to those attributes defined in the "Air travel demand" profile corresponding to the scenario under study.		Yes	High	
	10.4.3 Passenger behavioural model		No		
	Passenger agents shall simulate the actual behaviour of demand for a certain offer. *The criteria for passengers' flight choice for a certain O-D pair shall include airfare, flight duration, schedule delay, and the number of connected stops.*				
ACC-REQ-125	At the end of each simulation step the passenger agent shall determine the actual number of passengers of that type in each flight based on: - The total number of passengers of that type. - The passenger utility curve. - The passenger value of time. - The time of departure and time of arrival of the flights offered by airlines covering the OD pair.		Yes	High	The overall actual passengers demand of an OD pair is decomposed in a demand profile by time of the day and Passenger Class (e.g. 75% leisure, 25%business) and then allocated to single flights according to the actual level of competition and Actual Fares on the same route (e.g. by using discrete choice models).

Id	Definition	Rationale	IsReq	Level	Comments
	11. Exogenous Variables		No		
	Exogenous variables are used for setting arbitrary external conditions that affect the model but are not affected by it. The following variables shall be modelled as exogenous: *- Air travel demand* *- Fuel prices*				
	11.1 Air travel demand		No		
ACC-REQ-009	The forecasted passengers demand shall consist of a number of business passengers and leisure passengers, each with an utility curve and a value of time, at each simulation step and for each origin-destination pair.		Yes	High	As a future evolution, instead of being introduced as part of the scenario this could be estimated using a Gravity Model (or similar) to predict total passenger volume between two cities i and j, using as independent variables geo-economics factors such as population, catchment area, GDP, buying power, travel time, distance... (see Grosche et al., 2007). Forecasted demand should then change from year to year according to the evolution of such geo-economics factors.

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-066	The actual passengers demand shall be calculated as a deviation from the forecasted demand, according to the following formula: actual demand(t)=(1+x%)*forecast demand(t) with the value of x<>0 extracted from a probability distribution defined a priori.	This reflects the deviation from simulation step to simulation step, to be used in the calculation of actual profit.	Yes	High	
	11.2 Fuel prices		No		
ACC-REQ-192	The forecasted fuel price profile shall consist of a value in euros for each simulation step.	This allows to take into account the impact of variable fuel prices on airlines Direct Operating Costs.	Yes	High	
ACC-REQ-193	The actual fuel price profile shall be calculated as a deviation from the forecasted one, according to the following formula: actual fuel price(t)=(1+y%)*forecast fuel price with the value of y<>0 extracted from a probability distribution defined a priori.	This reflects the difference between actual and forecasted values due to the uncertainty in fuel price forecast.	Yes	High	
	12. Data repositories		No		
	The purpose of the data repositories is to provide persistence to both the data used to configure and execute simulations and the output data generated by the system. Information shall be persisted in an organised manner that allows complex manipulation and updateability of data schemes or contents if needed.				

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-010	All the configuration and output data shall be stored in a database.	Allows easier tracking and maintenance of the information.	Yes	High	Data include airport characteristics, aircraft characteristics, turnaround times, outputs, etc.
ACC-REQ-010.01	The technical architecture of the system shall provide a data repository where the system will store the data used during the execution.		Yes	Low	
ACC-REQ-022	The database shall only be accessible locally by the system web application.	Provides security and integrity to the data.	Yes	High	Access to the data will be needed for simulation execution (e.g. to load the characteristics of the airport(s) included in each scenario), but also for other purposes, such as analysis of simulation outputs, visualisation, etc.
ACC-REQ-022.01	A common server shall host the data repository engine and the application server.		Yes	Low	
ACC-REQ-022.02	The data repository shall implement an access control which only allows local connections to the repository.		Yes	Low	
ACC-REQ-023	The data shall be organised in the database following a relational model.	Allows an optimal organisation of the data.	Yes	High	
ACC-REQ-023.01	The data repository shall implement a relational database management system (RDBMS) and an interface using Structured Query Language (SQL).		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-243	The database shall ensure referential integrity.	Allows the return of complete data when querying.	Yes	High	Referential integrity is a property of data which, when satisfied, requires every value of one attribute (column) of a relation (table) to exist as a value of another attribute in a different (or the same) relation (table).
ACC-REQ-244	The database shall be normalised in the 3NF (Third Normal Form).	Reduces the duplication of data and ensures referential integrity.	Yes	High	For a table to comply with the 3NF: - It shall not contain any duplicate rows. - Each row shall have a unique identifier. - Each attribute shall contain only one value. - All the attributes shall be dependent on the primary key and only the primary key.
ACC-REQ-244.01	Each group of related data shall be stored in a separate table.		Yes	Low	
ACC-REQ-244.02	Each cell in a table shall contain only one piece of information.		Yes	Low	
ACC-REQ-244.03	The tables shall not contain any duplicate rows.		Yes	Low	
ACC-REQ-244.04	The tables shall have a unique identifier (primary key) to uniquely identify each row.		Yes	Low	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-244.05	All the attributes shall be dependent on the primary key and only the primary key.		Yes	Low	
	12.1 Airport data repository		No		
ACC-REQ-024	The airport data repository shall include a set of airports.	Allow the selection of the airports to be included in the different scenarios.	Yes	High	
ACC-REQ-024.01	The data repository shall contain at least one space to store airport data.		Yes	Low	
ACC-REQ-037	Each airport included in the airport data repository shall be assigned a value for each of the following attributes of the airport agents: - Airport identifier. - Position. - Airport type. - Airport level. - Coordination time interval. - Landing fee profile. - Opening/closing hours. - Arrival capacity profile. - Departure capacity profile. - Infrastructure capacity profile. - Rolling capacity time interval. - Rolling arrival capacity profile. - Rolling departure capacity profile. - Rolling infrastructure capacity profile. - Possibility of capacity expansion. - Possibility of landing fees modification. - Grandfather rights	Initialise the attributes of the airport agents to those of the airports selected to be included in the scenario.	Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
	12.2 Airline data repository		No		
ACC-REQ-033	The airline data repository shall include a set of airlines	Allow the selection of the airlines to be included in the different scenarios	Yes	High	
ACC-REQ-033.01	The data repository shall contain at least one space to store airlines data.		Yes	Low	
ACC-REQ-043	Each airline included in the airline data repository shall be assigned a value for each of the attributes of the airline agents: - Airline identifier. - Airline business model. - Hubs. - Fleet composition. - Operational costs factors. - Alliance.	Initialise the attributes of the airline agents to those of the airlines selected to be included in the scenario.	Yes	High	
	12.3 Aircraft data repository		No		
	The aircraft data repository shall define the main characteristics relevant for the slot allocation problem of a list of real aircraft types as well as for a set of imaginary, prototypical aircraft types. The characteristics that will be considered are: *- Aircraft model.* *- Seating capacity.* *- Fuel consumption.* *- Cruise speed.* *- Direct operating cost.*				
ACC-REQ-030	Each aircraft type included in the aircraft data repository shall be uniquely identified.		Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-031	Each aircraft type included in the aircraft data repository shall be assigned a seating capacity in number of passengers.		Yes	High	
ACC-REQ-034	Each aircraft type included in the aircraft data repository shall be assigned a fuel consumption in kg per km.	Use this value in the BHDOC calculation.	Yes	High	
ACC-REQ-149	Each aircraft type included in the aircraft data repository shall be assigned a cruise speed in km per hour.	Use this value in the calculation of the flight duration	Yes	High	
ACC-REQ-032	Each aircraft type included in the aircraft data repository shall be assigned an Average Block Hour Direct Operating Cost (BHDOC) in euro per kilometre.	Use this value in BHDOC calculation.	Yes	High	
ACC-REQ-300	Each aircraft type included in the aircraft data repository shall be assigned a range in km.		Yes	High	
	12.4 Turnaround data repository		No		
ACC-REQ-036	The turnaround time of each aircraft type at each airport and for each airline shall be uniquely identified.		Yes	High	
ACC-REQ-041	The turnaround time of each triad (aircraft type, airport, and airline) shall be assigned a value in minutes.	Turnaround time is needed to check the compatibility between an arrival slot and a departure slot at the same airport for two consecutive flights of the same aircraft.	Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
	12.5 Route data repository		No		
ACC-REQ-039	Each route shall be uniquely identified.		Yes	High	
ACC-REQ-042	Each route shall be defined as a pair (airport of origin, airport of destination).		Yes	High	
ACC-REQ-040	Each route shall be assigned a length defined in kilometres.	Allow the computation of the duration of the flight as a function of the aircraft type. Flight duration is needed to check the compatibility between a departure slot at the origin.	Yes	High	
	SYSTEM ARCHITECTURE				
	A scheme of the system architecture is shown in Annex V System architecture.		No		
	13. Software		No		
	The Software System Architecture shall define the main characteristics of the software solution to be used. *The main elements of the architecture are the following:* *- Agent-Based System/Object-Oriented Paradigm.* *- 3-Tier Client-Server architecture, implemented using a Model-View-Controller Web Based Application.* *- Java Programming Language and Spring Framework (open source application framework for Java).* *- Apache Tomcat Servlet Container.*		No		

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-209	The system shall follow the Agent Based/Object Oriented Paradigm rules: - Encapsulation: integrating state (data) and behaviour (methods) in abstract data types (objects). - Allowing inheritance and polymorphism.		Yes	High	
ACC-REQ-109	The system shall implement a Model View Controller (MVC) pattern with a clear separation between the presentation layer, the business logic and the data access.	Allows modularity and the upgrade or replacement of any of the layers.	Yes	High	
ACC-REQ-174	The MVC pattern shall be implemented by using the Java Spring framework.	Abstracts complex modules such as data access, transactions or security and allows fast construction of complex applications.	Yes	High	
ACC-REQ-070	The system shall be implemented as a web application.	Provides cross platform compatibility, requires no infrastructure at the client side and allows transparent upgrades.	Yes	High	
ACC-REQ-020	The system persistence layer shall be coded in the Java programming language.	Java has a vast array of 3rd party libraries documentation and developer community, is platform ubiquitous and easier to learn than other languages like C++.	Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-175	The system application layer shall be coded in the Java programming language.	Java has a vast array of 3rd party libraries documentation and developer community, is platform ubiquitous and easier to learn than other languages like C++.	Yes	High	
ACC-REQ-074	The system presentation layer shall be coded using HTML, Javascript and CSS.	HTML + CSS + Javascript allows the creation of rich web interfaces that are compatible with all browsers.	Yes	High	
ACC-REQ-073	The system shall be deployed in an Apache Tomcat Servlet Container.	Apache Tomcat features a light and efficient web server and servlet container that can host complex applications.	Yes	High	
ACC-REQ-001	The system configuration options shall be configurable by using an external text property file that shall contain: - The database connection details. - Any external system connection details. The format of the configuration options file shall be: "property name"="property value" (e.g. database.IP=172.0.0.1)	Allow configuration changes without modifying the code and thus force recompiling.	Yes	High	
ACC-REQ-063	The system messages displayed on the application interface shall be stored in an external text property file.	Allow text changes without modifying the code and thus force recompiling.	Yes	High	

Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-298	The format of the configuration options file shall be: "message name"="message value" (e.g. welcome.message=Welcome to ACCESS)	Allow text changes without modifying the code and thus force recompiling.	Yes	High	
ACC-REQ-006	The system shall be operated by means of a graphical user interface.	Provide a user-friendly interface.	Yes	High	
ACC-REQ-104	The system shall provide a secure login	Provides control and security to the use of the system and the data stored in it.	Yes	High	
ACC-REQ-228	Each user shall have an account login and password to access the system that shall be provided by the system administrator.	Provides control and security to the use of the system and the data stored in it.	Yes	High	
ACC-REQ-121	The system shall have a logging system to record all the operations and events.	Find errors and evaluate the correct execution of the system operations.	Yes	High	
ACC-REQ-287	Every user input shall be validated by the system.	Avoid input errors and misconfigurations.	Yes	High	
	14. Hardware		No		
	The Hardware System Architecture shall define the main characteristics of the hardware solution to be used. *The main elements of the architecture are the following:* *- A centralised server that can be remotely accessed by all the users of the system through a web application* *- A network solution that provides 24/7 access through the Internet.* *- The ability to scale the server and network capacity if needed.*		No		

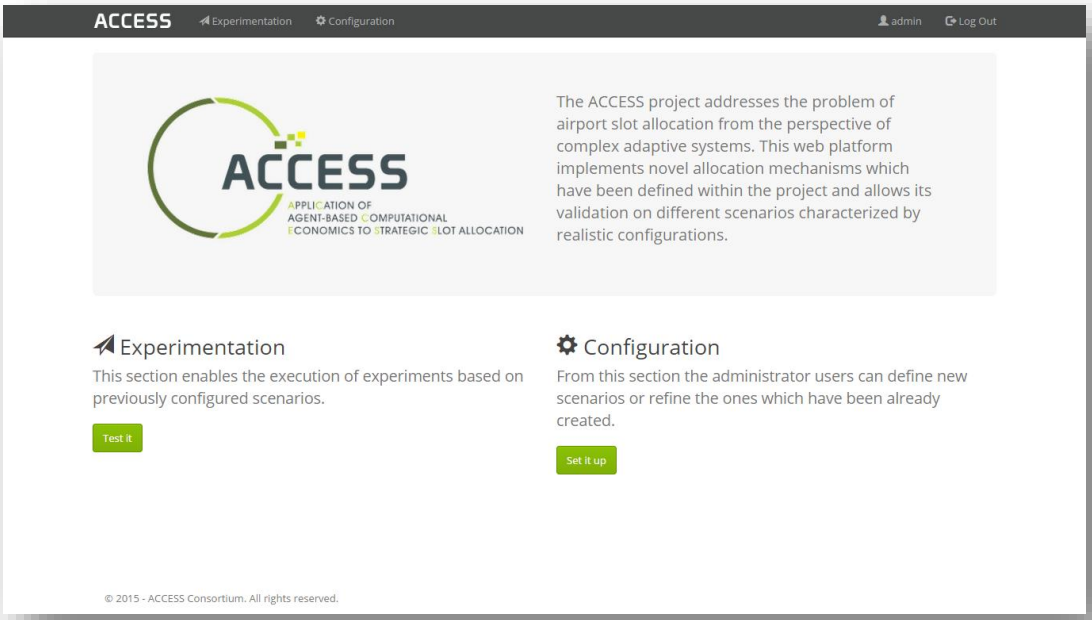
Id	Definition	Rationale	IsReq	Level	Comments
ACC-REQ-229	The system shall be installed in a centralised server.	Allow all the users to access the same and updated application and data.	Yes	High	
ACC-REQ-230	The server shall have access through Internet connectivity 24/7.	Allow the users to access the application at anytime from anywhere.	Yes	High	
ACC-REQ-231	The server shall have an uptime availability of at least 99%.		Yes	High	
ACC-REQ-238	The server Internet connectivity shall be broadband of at least 10Mb/1Mb.	Allow the connection of multiple concurrent users to the system	Yes	High	
ACC-REQ-239	The server network connectivity shall be at least Gigabit.		Yes	High	
ACC-REQ-240	The server shall be component/power upgradable.	Cope with growing number of users or for fastest calculation if needed.	Yes	High	
ACC-REQ-241	The server shall have at least 4 CPU or Virtual CPU cores.		Yes	High	
ACC-REQ-107	The server shall have at least 4GB of physical or Virtual RAM.		Yes	High	
ACC-REQ-108	The server shall have at least 40GB of storage space.		Yes	High	

Annex I. Front end prototype

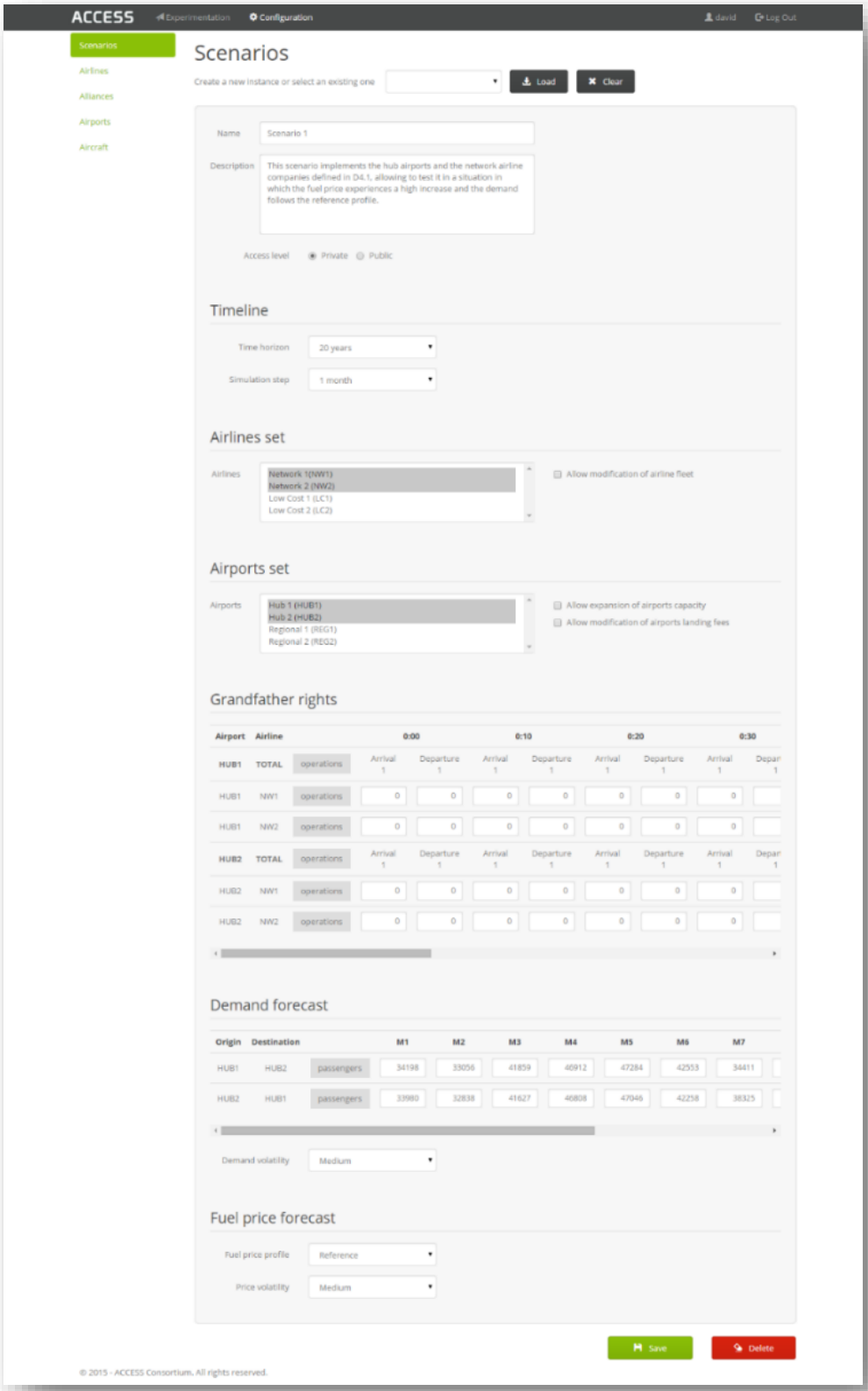
The main screenshots of the prototype are presented below:

Login:

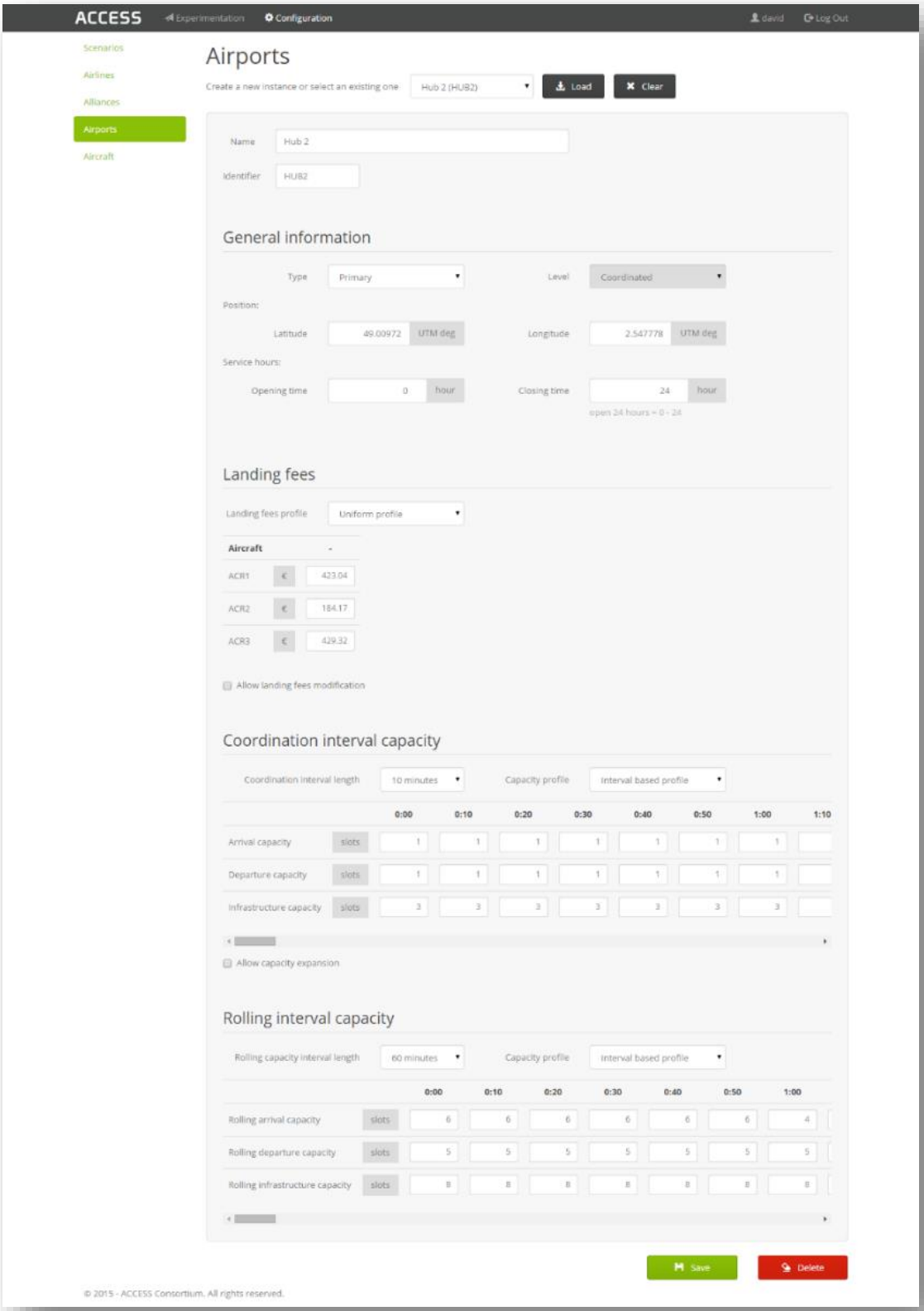
Main screen:



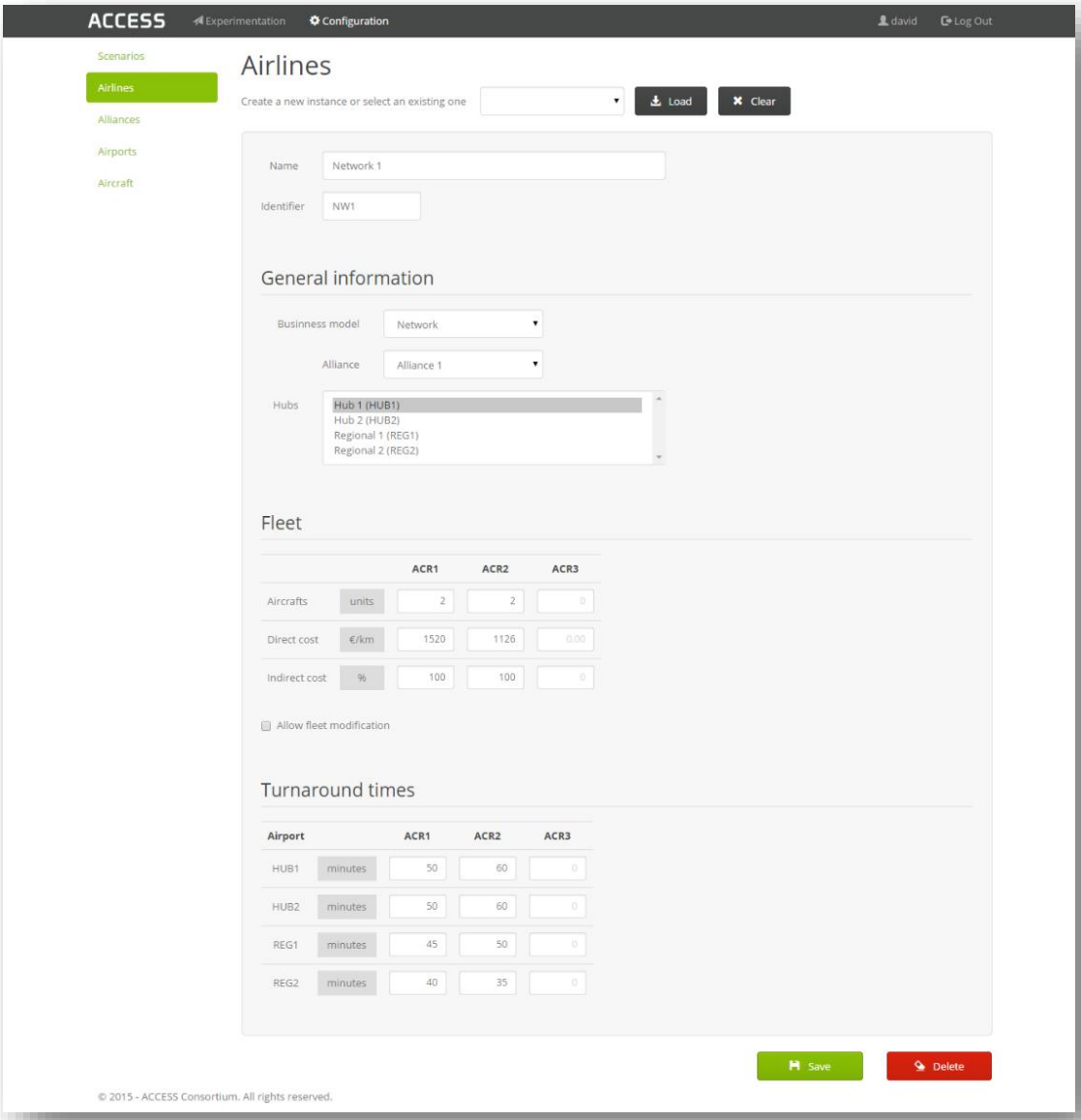
Configuration - Scenarios:



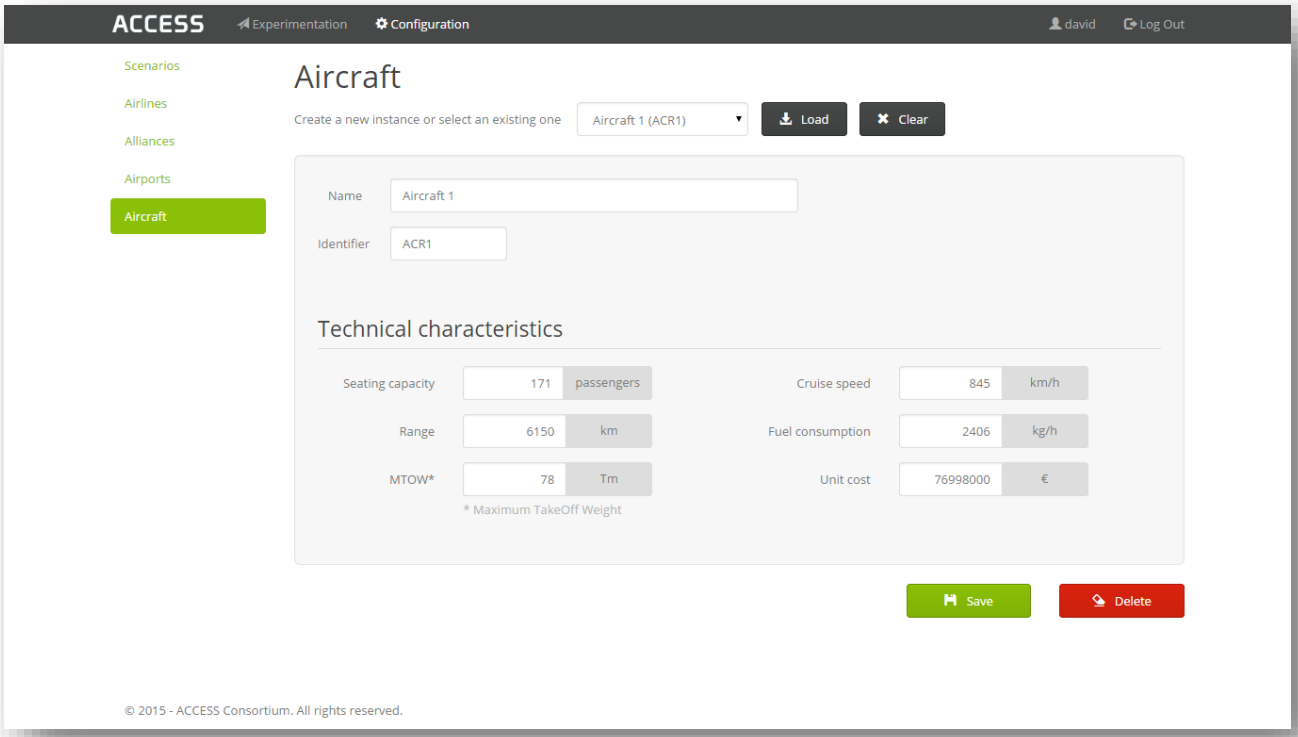
Configuration –Airports:



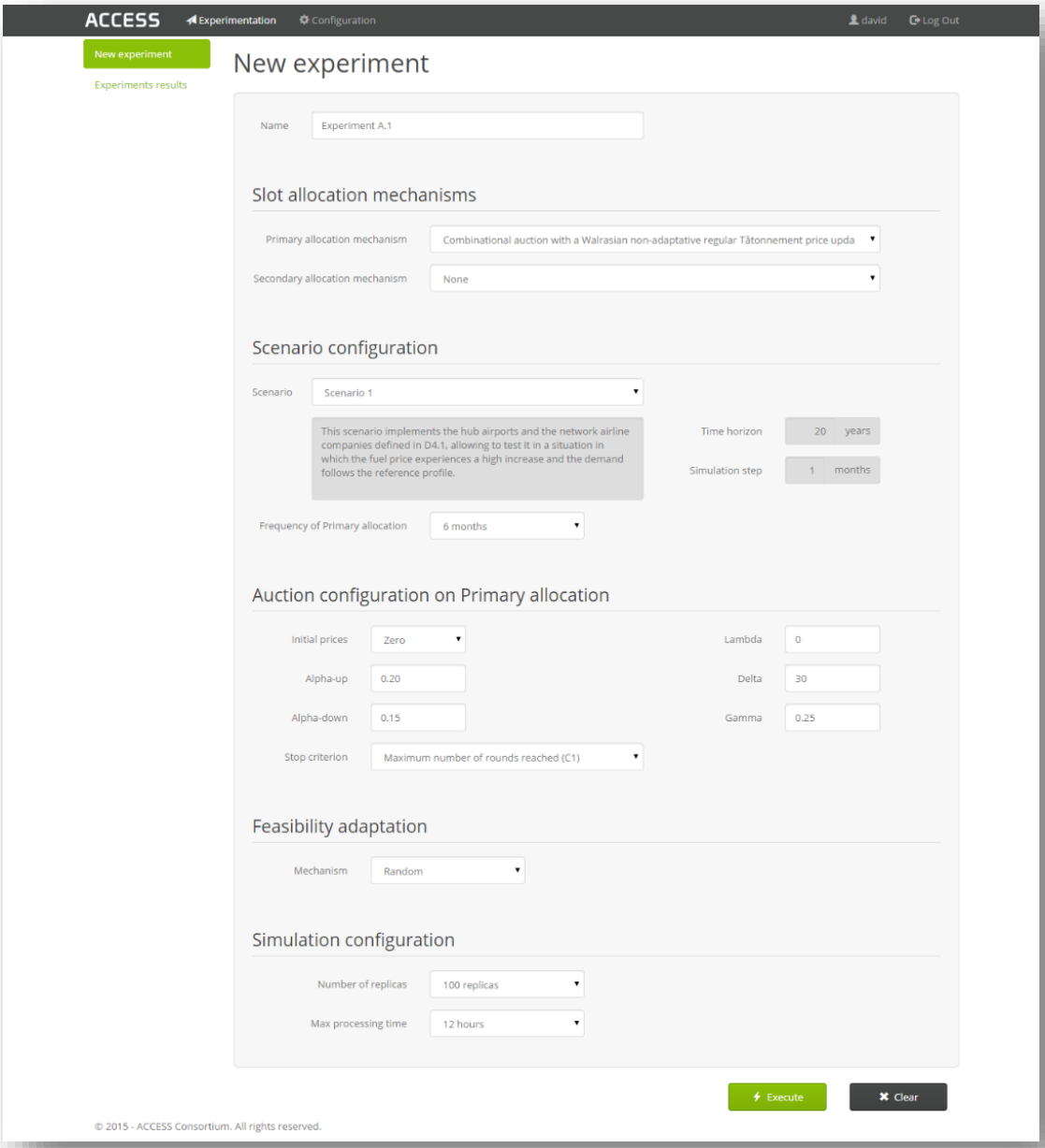
Configuration –Airlines:



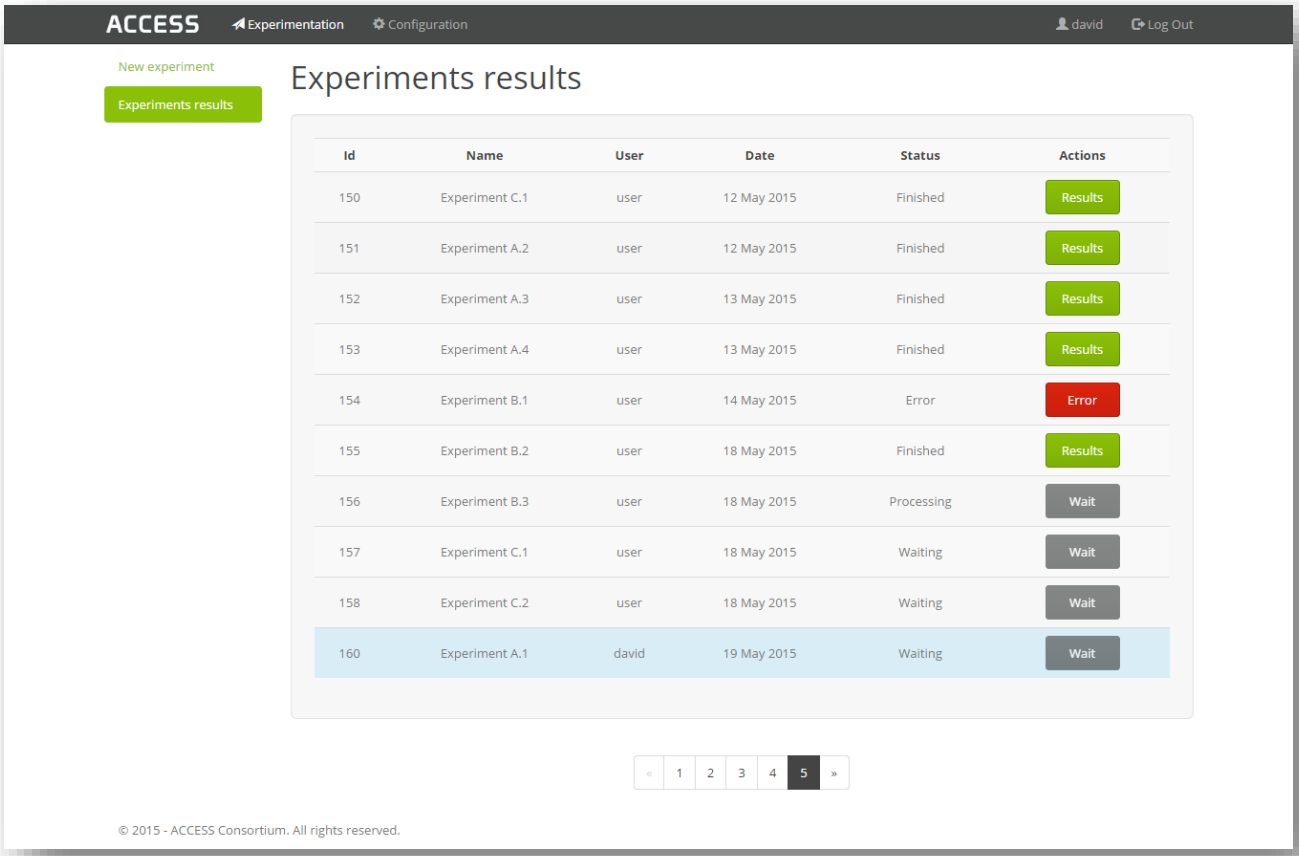
Configuration –Aircraft:



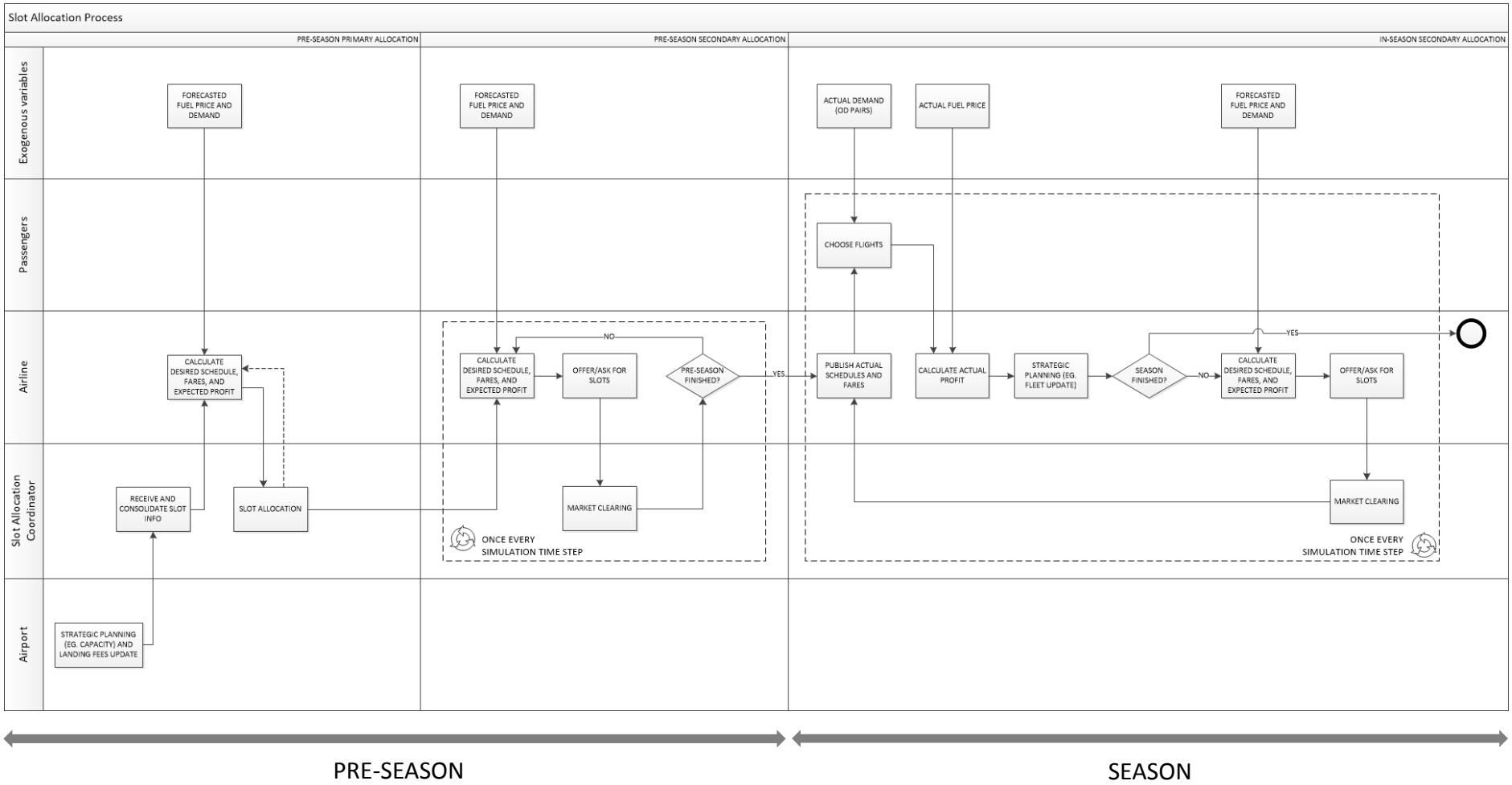
Experimentation –New experiment:



Experimentation –Experiment results:



Annex II. General simulation logic



Annex III. Formulation of the optimisation model

Terminology

Notation	Explanation
M	Demand to satisfy, that is, set of movements requiring a slot at Level 3 European airports in the scheduling interval considered
A	Set of Level 3 European airports in which movements in M occur
U	Set of the airspace users that require movements in M.
M_u^a	Subset of M including the movements at airport $a \in A$ requested by user $u \in U$.
$\tilde{M}^2$	Subset of $M \times M$ including the pairs of turnaround movements, that is, pairs (m,m') made of an arrival m and of an immediately successive departure m' of the same aircraft at the same airport.
U_n^a , U_h^a	Subsets of U including respectively the new entrant and the incumbent (historic) airspace users at airport $a \in A$.
I_n^a , I_h^a	Sets of time intervals in which the scheduling interval is partitioned in accordance with the new entrant and the incumbent (historic) airspace users' interests at airport $a \in A$ respectively.
S	Set of available slots at the airports in A to satisfy the demand M.
S^a	Subset of S including the available slots at airport $a \in A$.
SS_s	Set of subslots included in slot $s \in S$.
t_{ss}	Start time of subslot $ss \in SS$, for $s \in S$.
c_s^a	Maximum number of movements that can occur at airport $a \in A$ in the interval of occurrence of each subslot in $s \in S^a$
c_t^a , $\underline{c}_t^a$, $\bar{c}_t^a$	Maximum number of total, arrival and departure movements per hour, respectively, which can occur at airport $a \in A$ starting from minute t.
$g_{u,i}^a$	Minimum number of slots granted to user $u \in U$ at airport $a \in A$ during time interval $i \in I_n^a \cup I_h^a$
o_m, d_m	Origin and destination airport of movement $m \in M$, respectively. Either o_m or d_m certainly belongs to A for all $m \in M$. However it is not necessarily true that both o_m and d_m belong to A because M may also include also movements associated to flights to/from Level 1 and Level 2 European airports and extra-European airports.
$\hat{t}_m$	Start time of requested subslot by movement $m \in M$
$bsc_m(ss)$	Backward shift cost for assigning movement $m \in M$ a subslot ss with an earlier start time than $\hat{t}_m$. $bsc_m(ss)$ is equal to 0 if $t_{ss} \geq \hat{t}_m$ and it is a linearly increasing function of $\hat{t}_m - t_{ss}$ otherwise. The linearity assumption may hold for 'small' deviations from $\hat{t}_m$ only.
$fsc_m(ss)$	Forward shift cost for assigning movement $m \in M$ a subslot ss with a later start time than $\hat{t}_m$. $fsc_m(ss)$ is equal to 0 if $t_{ss} \leq \hat{t}_m$ and it is a linearly increasing function of $t_{ss} - \hat{t}_m$ otherwise. The linearity assumption may hold for 'small' deviations from $\hat{t}_m$ only.
tt_m , $\underline{tt}_m$, $\overline{tt}_m$	optimal, minimal feasible, and maximum feasible travel time, respectively, between airports o_m and d_m for movement $m \in M$.

Notation	Explanation
$btdc_m(t)$	Backward travel time cost: it is the cost for an actual travel time t less than tt_m for movement $m \in M$. $btdc_m(t)$ is equal to 0 if $t \geq tt_m$ and it is a linearly increasing function of $tt_m - t$ otherwise. The linearity assumption may hold for 'small' deviations from tt_m only.
$ftdc_m(t)$	Forward travel time cost: it is the cost for an actual travel time t greater than tt_m for movement $m \in M$. $ftdc_m(t)$ is equal to 0 if $t \leq tt_m$ and it is a linearly increasing function of $t - tt_m$ otherwise. The linearity assumption may hold for 'small' deviations from tt_m only.
$tot_{m,m'}$	Turnaround time for $(m,m') \in \tilde{M}^2$
Q_m	Cost of cancellation of movement $m \in M$

Decision variables

$$y_m = \begin{cases} 1 & \text{if movement } m \text{ is canceled} \\ 0 & \text{otherwise} \end{cases} \qquad \forall m \in M$$

$$x^a_{ss,m} = \begin{cases} 1 & \text{if subslot } ss \text{ is assigned to movement } m \text{ at airport } a \\ 0 & \text{otherwise} \end{cases} \qquad \forall m \in M, a \in \{o_m, d_m\} \cap A, ss \in S^a$$

Objective function

$$\min \sum_{m \in M} Q_m y_m + \sum_{m \in M: o_m \notin A} \sum_{ss \in SS_s : s \in S^{d_m}} bsc_m(x^{d_m}_{ss,m}) + fsc_m(x^{d_m}_{ss,m}) + \sum_{m \in M: o_m \in A} \sum_{ss \in SS_s : s \in S^{o_m}} bsc_m(x^{o_m}_{ss,m}) + fsc_m(x^{o_m}_{ss,m}) +$$
$$+ \sum_{m \in M: o_m, d_m \in A} \left(btdc_m \left(\sum_{ss \in SS_s : s \in S^{d_m}} t_{ss} x^{d_m}_{ss,m} - \sum_{ss \in SS_s : s \in S^{o_m}} t_{ss} x^{o_m}_{ss,m} \right) + ftdc_m \left(\sum_{ss \in SS_s : s \in S^{d_m}} t_{ss} x^{d_m}_{ss,m} - \sum_{ss \in SS_s : s \in S^{o_m}} t_{ss} x^{o_m}_{ss,m} \right) \right)$$

1. The first term penalises the cancelation of movements.
2. The second term penalises the early or the late arrival of movements with origin outside A.
3. The third term penalises the early or the late departure of movements with origin in A.
4. The fourth term penalises the deviation from the optimal travel time for movements with both origin and destination in A.

Terms 2-4 describe all possibilities for modelling the costs of (sub)slot allocations different from the requested ones in European Level 3 airports (represented by the set A). In fact, the third term represents all movements departing from an airport in A. Movements arriving in an airport in A can either depart from an airport outside A (second term) or from another airport in A (fourth term). The flight duration is considered in the fourth term to link the slot allocation across different airports (simultaneous allocation).

Cancellation costs Q_m and the proportional factors of the earliness and tardiness costs for departure times and travelling times must be given as input to the model. They depend on the movement m considered and on the origin and destination airports of the associated flight.

Constraints

The following sets of constraints must be satisfied

1. Both movements of each flight must have a slot assigned if both origin and destination airports are in *A*.

$$y_m = y_{m'} \quad \forall m, m' \in M : m \text{ and } m' \text{ are the two movements of the same flight}$$

2. Each movement needs exactly one subslot for being operated

$$\sum_{ss \in SS_s : s \in S^a} x^a_{ss,m} = 1 - y_m \quad \forall m \in M, a \in \{o_m, d_m\} \cap A$$

3. Capacity constraint on the overall number of movements that can be operated in each subslot length

$$\sum_{m \in M : a \in \{o_m, d_m\}} \sum_{ss \in SS_s : s \in S^a} x^a_{ss,m} \le c^a_s \quad \forall a \in A, s \in S_a$$

4. Bundle constraints on the maximum number of overall movements per hour

$$\sum_{m \in M : a \in \{o_m, d_m\}} \sum_{ss \in SS_s : t_{ss} \in [k, k+55]} x^a_{ss,m} \le c^a_t \quad \forall a \in A, t = 0,5,10,\ldots,1435$$

5. Bundle constraints on the maximum number of arrival movements per hour

$$\sum_{m \in M : a \in \{d_m\}} \sum_{ss \in SS_s : t_{ss} \in [k, k+55]} x^a_{ss,m} \le \underline{c}^a_t \quad \forall a \in A, t = 0,5,10,\ldots,1435$$

6. Bundle constraints on the maximum number of departure movements per hour

$$\sum_{m \in M : a \in \{o_m\}} \sum_{ss \in SS_s : t_{ss} \in [k, k+55]} x^a_{ss,m} \le \overline{c}^a_t \quad \forall a \in A, t = 0,5,10,\ldots,1435$$

Constraints (4) to (6) apply to all the 24 one-hour-long intervals that occur in a day and starts every five minutes. Since a day is composed of 1440 minutes, the starting time of a subslot varies from 0 to 1435 with a five-minute step.

7. Coherent subslots must be assigned to each movement at its origin and destination airports if both are Level 3 European airports.

$$\sum_{ss \in SS_s : s \in S^{d_m}} t_{ss} x^{d_m}_{ss,m} - \sum_{ss \in SS_s : s \in S^{o_m}} t_{ss} x^{o_m}_{ss,m} \le \overline{tt}_m \quad \forall m \in M : o_m, d_m \in A$$

$$\sum_{ss \in SS_s : s \in S^{d_m}} t_{ss} x^{d_m}_{ss,m} - \sum_{ss \in SS_s : s \in S^{o_m}} t_{ss} x^{o_m}_{ss,m} \ge \underline{tt}_m \quad \forall m \in M : o_m, d_m \in A$$

8. Coherent subslots must be assigned to each pair of turnaround movements

$$\sum_{ss \in SS_s : s \in S^{o_m}} t_{ss} x^{o_m}_{ss,m'} - \sum_{ss \in SS_s : s \in S^{d_m}} t_{ss} x^{d_m}_{ss,m} \ge tot_{m,m'} \quad \forall m, m' \in \tilde{M}^2$$

9. At each Level 3 airport each incumbent airspace user must get a number of subslots at least equal to its historic rights in each time interval of interest for incumbent airspace users.

$$\sum_{m \in M_u^a} \sum_{ss \in SS_s : s \in S^a, t_{ss} \in i} x_{ss,m}^a \geq g_{u,i}^a \quad \forall a \in A, i \in I_h^a, u \in U_h^a$$

These constraints impose the incumbent airspace user's right to retain a series of slots on the basis of historic precedence.

- $g_{u,i}^a$ are equal to the number of subslots that are eligible for historic rights to user *u* in the interval *i* at airport *a*.
- In accordance with requirement ACC-288 and to take into account possible deviations of current slots' start times with respect to the past requested slots, the set I_h^a usually includes time intervals longer than a slot length. As an example, such intervals may coincide with the peak and off-peak times of the specific airport.

10. At each Level 3 airport the new entrant users must be assigned a minimum number of subslots

$$\sum_{u \in U_n^a} \sum_{m \in M_u^a} \sum_{ss \in SS_s : s \in S^a} x_{ss,m}^a \geq \sum_{u \in U_n^a} g_{u,i}^a \quad \forall a \in A, i \in I_n^a$$

These constraints impose the new entrants' collective right to have allocated the 50% of the slots non-assigned on the basis of historic rights, unless their requests are less than 50%.

- I_n^a usually contains intervals longer than a slot length to take into account that there may not be any free slot in some time interval, e.g., during peak times
- $\sum_{u \in U_n^a} g_{u,i}^a$ are equal to the maximum between the number of subslots that are free in the intervals i at airports *a* and the ones requested in the same intervals at the same airports by the new entrants.

Annex IV. Combinatorial auction specification

Notation

The following notation applies:

- S_m: set of all allowed feasible combinatorial bids for any airline request.
- M: total number of combinatorial requests made by the airlines.
- K: number of airports (k index to identify each airport $k \in K / k = \{1,2,\dots,K\}$).
- T: number of "coordination time intervals", each of them noted by the subindex $t = \{1,2,\dots,T-1\}$.
- s_m: combinatorial request m. Each request $s_m \in S_m \ / \ m = \{1,2,\dots,M\}$ corresponds to a slot-level schedule which includes time intervals for f_m flight movements (flight movement → linked arrival + departure in the same airport) in total, with f_{mk} flight movements in each airport $k \in K$. This is, the request of $(\overline{ta_{mk}})$ slots for f_{mk} arrivals and $(\overline{td_{mk}})$ slots for their f_{mk} corresponding departures in each airport k. The utility of the combinatorial request m is reached only if airline receive all the slots requested in m.
- $s_m^{0)}$ first combinatorial request m which includes the initial preferences of the airline that originates it.
- $s_m^{i)}$ combinatorial request m rebuilt by the airline that originated it for the iteration i) of the auction.
- $s^{i)}$ set of all rebuilt combinatorial requests for the iteration i) of the auction ($s^{i)} = \bigcup_{m=1}^{M} s_m^{i)}$).
- $s_{feasible}^{i)}$ feasible set of combinatorial requests built from the set of combinatorial requests for the auction iteration i).
- a_{mf}: arrival airport for the flight movement f in the combinatorial request $m \in M$.
- $\delta_m^{i)}$: auxiliary variable, set to 1 if the combinatorial request m is allocated in iteration i).
- H: number of rolling capacity constraints. Each rolling capacity constraint $h = \{1,2,\dots,H\}$ affects T_h consecutive time intervals. If $T_h = 1$, that constraint would be equivalent to a normal capacity constraint.
- ac_{htk}: arrival capacity of restriction h in airport $k \in K$. Number of arrivals allowed in the set of intervals from (t) to $(t + T_h - 1)$. If $T_h = 1$, the restriction will be referred to a single coordination time interval (→number of arrivals allowed in one interval t).
- dc_{htk}: departure capacity of restriction h in airport $k \in K$. Number of departures allowed in the set of intervals from (t) to $(t + T_h - 1)$.
- tc_{htk}: total capacity of restriction h in airport $k \in K$. Number of allocations (departures + arrivals) allowed in the set of intervals from (t) to $(t + T_h - 1)$.
- wa_{mf}: penalty or cost of the time offset for the arrival of a flight movement f in airport $k \in K$ in combinatorial request m.
- wd_{mf}: penalty or cost of the time offset for the departure of a flight movement f in airport $k \in K$ in combinatorial request m
- $ta_{mf}^{i)}$: iteration i) coordination time interval requested for the arrival of the flight movement f (parameter) in airport $k \in K$ in combinatorial request m.
- $td_{mf}^{i)}$: iteration i) coordination time interval requested for the departure of the flight movement f (parameter) in airport $k \in K$ in combinatorial request m.
- $tra_{mf} = ta_{mf}^{0)}$: coordination time interval initially requested for arrival of the flight movement f (parameter) in airport $k \in K$ in combinatorial request m.

- $trd_{mf} = td_{mf}^{0)}$: coordination time interval initially requested for departure of the flight movement f (parameter) in airport $k \in K$ in combinatorial request m.
- $\delta a_{tmkf}^{i)}$: auxiliary variable, set to 1 if the arrival of the flight movement f in airport $k \in K$ in combinatorial request m is assigned to interval t in iteration i).
- $\delta d_{tmkf}^{i)}$: auxiliary variable, set to 1 if the departure of the flight movement f in airport $k \in K$ in combinatorial request m is assigned to interval t in iteration i).
- $P_m^{i)}\left(s_m^{i)}\right)$: payment for the requested slots in $s_m^{i)}$ allocated to the combinatorial request m. It is function of the current prices ($pa_{t,k}^{i)}$, $pd_{t,k}^{i)}$) of the requested slots:

$$P_m^{i)}\left(s_m^{i)}\right) = \sum_{k=1}^{K}\sum_{t=0}^{T-1}\left(pa_{tk}^{i)} \cdot \sum_{f=1}^{f_{mk}} \delta a_{tmkf}^{i)} + pd_{tk}^{i)} \cdot \sum_{f=1}^{f_{mk}} \delta d_{tmkf}^{i)}\right)$$

Mathematical specification

The combinatorial auction mechanism for airport slots allocation follows the next mathematical specification:

Step 0.	Initialization: The *coordinator* (auctioneer) sets iteration counter $i = 0$, initialises the slot price multipliers (default values or previous auction results) and computes the initial prices[1][2]: $\lambda a_{htk}^{0)} = 0,\ \lambda d_{htk}^{0)} = 0,\ \lambda t_{htk}^{0)} = 0 \Rightarrow pa_{tk}^{0)} = 0\,, pd_{tk}^{0)} = 0\ \forall k \in K, t \in (0, T-1).$ Each *airline* calculates its preferred combinations of arrival and departure slots without considering slot prices. These combinations will be saved as the airlines' initial preferences $s_m^{0)}$.
Step 1.	The coordinator announces the current slots prices to airlines. Each *airline manager* elaborates its slot requests $s_m^{i)}$ according to its objective functions, taking into account the slot prices of the current iteration, ($pa_{tk}^{i)}$, $pd_{tk}^{i)}$), and the payment function ($\Rightarrow P_m^{i)}(s_m^{i)}$) provided by the coordinator. The requests shall respect the sequence and time constraints between arrivals and departures at different airports. Each airline submits its slot request $s_m^{i)}$ to the coordinator. Each slot request $s_m^{i)}$ corresponds to a slot-level schedule (a combination of arrival slots $(\overline{ta_{mk}})$ and their corresponding departure slots $(\overline{td_{mk}})$).
Step 2.	The auctioneer aggregates the slot requests $s_m^{i)}$ of all the airlines at each airport, $s^{i)}(= \cup_{m=1}^{M} s_m^{i)})$, for arrivals, departures and total operations. These aggregated slot requests will be compared with the airport's capacity constraints in *Step 3*.
Step 3.	The auctioneer updates the *price adjustment factor* $\alpha^{i)}$ if necessary (when using *adaptive tâtonnement* updating price schemes).

[1] If there was a previous combinatorial auction, the process can start from the results of this auction ($\lambda a'^{\text{end)}}_{htk}, \lambda d'^{\text{end)}}_{htk}, \lambda t'^{\text{end)}}_{htk}$):

$$\lambda a_{htk}^{0)} = \lambda a'^{\text{end)}}_{htk},\ \lambda d_{htk}^{0)} = \lambda d'^{\text{end)}}_{htk},\ \lambda t_{htk}^{0)} = \lambda t'^{\text{end)}}_{htk} \Rightarrow pa_{tk}^{0)} = pa'^{\text{end)}}_{tk}\,, pd_{tk}^{0)} =, pd'^{\text{end)}}_{tk}\ \forall k \in K, t \in (0, T-1).$$

[2] For Simultaneous Descending Auction, the process shall start from sufficiently large multiplier values to allow every price to decrease along the iterations:

$$\lambda a_{htk}^{0)} \gg 0,\ \lambda d_{htk}^{0)} \gg 0,\ \lambda t_{htk}^{0)} \gg 0.$$

Step 4. For each airport k, coordination time interval $t = 1, \dots, T-1$, and airport rolling constraint $h \in H$ the coordinator (auctioneer) takes the the aggregated slot requests obtained in *Step 2* and computes the difference between capacity and demand (arrivals, departures and total operations according to the following expressions:

$$\begin{cases} ga_{htk}^{i)} = \left(\sum_{m=1}^{M}\sum_{f=1}^{f_{mk}}\sum_{\tau=t}^{t+\mathrm{T}_h-1}\delta a_{\tau mkf}\right) - ac_{htk} \\ gd_{htk}^{i)} = \left(\sum_{m=1}^{M}\sum_{f=1}^{f_{mk}}\sum_{\tau=t}^{t+\mathrm{T}_h-1}\delta d_{\tau mkf}\right) - dc_{htk} \\ gt_{htk}^{i)} = \left(\sum_{m=1}^{M}\sum_{f=1}^{f_{mk}}\sum_{\tau=t}^{t+\mathrm{T}_h-1}(\delta a_{\tau mkf} + \delta d_{\tau mkf})\right) - tc_{htk} \end{cases}$$

Then, the coordinator updates the "multipliers" for next iteration $i+1)$ with the following expressions that shall be particularised depending on the auction mechanism as it is explained:

$$\begin{cases} \lambda a_{htk}^{i+1)} = \max\left\{0, \lambda a_{htk}^{i)} + \alpha_a^{i)} \cdot ga_{htk}^{i)}\right\} \\ \lambda d_{htk}^{i+1)} = \max\left\{0, \lambda d_{htk}^{i)} + \alpha_d^{i)} \cdot gd_{htk}^{i)}\right\} \\ \lambda t_{htk}^{i+1)} = \max\left\{0, \lambda t_{htk}^{i)} + \alpha_t^{i)} \cdot gt_{htk}^{i)}\right\} \end{cases}$$

1- For the Walrasian Auction:

$$\begin{cases} \alpha_a^{i)} = \begin{cases} \alpha_+^{i)} & if\ \ ga_{htk}^{i)} \geq 0 \\ \alpha_-^{i)} & otherwise \end{cases} \\ \alpha_d^{i)} = \begin{cases} \alpha_+^{i)} & if\ \ gd_{htk}^{i)} \geq 0 \\ \alpha_-^{i)} & otherwise \end{cases} \\ \alpha_t^{i)} = \begin{cases} \alpha_+^{i)} & if\ \ gt_{htk}^{i)} \geq 0 \\ \alpha_-^{i)} & otherwise \end{cases} \end{cases}$$

2- For the Simultaneous Ascending Auction:

$$\begin{cases} \alpha_a^{i)} = \begin{cases} \alpha_+^{i)} & if\ \ ga_{htk}^{i)} \geq 0 \\ 0 & otherwise \end{cases} \\ \alpha_d^{i)} = \begin{cases} \alpha_+^{i)} & if\ \ gd_{htk}^{i)} \geq 0 \\ 0 & otherwise \end{cases} \\ \alpha_t^{i)} = \begin{cases} \alpha_+^{i)} & if\ \ gt_{htk}^{i)} \geq 0 \\ 0 & otherwise \end{cases} \end{cases}$$

3- For the Simultaneous Descending Auction:

$$\begin{cases} \alpha_a^{i)} = \begin{cases} \alpha_-^{i)} & if\ \ ga_{htk}^{i)} \leq 0 \\ 0 & otherwise \end{cases} \\ \alpha_d^{i)} = \begin{cases} \alpha_-^{i)} & if\ \ gd_{htk}^{i)} \leq 0 \\ 0 & otherwise \end{cases} \\ \alpha_t^{i)} = \begin{cases} \alpha_-^{i)} & if\ \ gt_{htk}^{i)} \leq 0 \\ 0 & otherwise \end{cases} \end{cases}$$

Finally, the coordinator updates each slot t price at each airport k for next iteration $i+1)$:

$$\begin{cases} pa_{tk}^{i+1)} = \sum_{h\in H_t}\sum_{\tau=t-T_h+1}^{t}\left(\lambda a_{htk}^{i+1)} + \lambda t_{htk}^{i+1)}\right) \\ pd_{tk}^{i+1)} = \sum_{h\in H_t}\sum_{\tau=t-T_h+1}^{t}\left(\lambda d_{htk}^{i+1)} + \lambda t_{htk}^{i+1)}\right) \end{cases}$$

$$h = 1,2,\cdots,H; k = 1,2,\cdots,K; t = 0,\dots,T-T_h$$

Step 5.	The auctioneer checks the stop criteria: -If the stop criteria is not met, the auctioneer goes to *Step 2* and starts the next iteration $i) = i + 1)$. -If the stop criteria is met, the coordinator stops the auction and starts the "feasibility restore mechanism" with the current slot allocation $s^{i)} \rightarrow s^{i)}_{feasible}$. After this, the coordinator announces the final slot allocation $s^{i)}_{feasible}$ for each airport and airline.

Annex V. Feasibility mechanism

Notation

The following notation applies:

- s_m: combinatorial request m. Each request $s_m \in S_m \ / \ m = \{1,2,\dots,M\}$ corresponds to a slot-level schedule which includes time intervals for f_m flight movements (flight movement → linked arrival + departure in the same airport) in total, with f_{mk} flight movements in each airport $k \in K$. This is, the request of $(\overline{ta_{mk}})$ slots for f_{mk} arrivals and $(\overline{td_{mk}})$ slots for their f_{mk} corresponding departures in each airport k. The utility of the combinatorial request m is reached only if airline receive all the slots requested in m.
- $s_m^{0)}$ first combinatorial request m which includes the initial preferences of the airline that originates it.
- $s_m^{i)}$ combinatorial request m rebuilt for the iteration $i)$ of the auction by the airline that originated it.
- $s^{i)}$ schedule (feasible or not) made by adding all rebuilt combinatorial requests by airlines for the iteration $i)$ of the auction ($s^{i)} = \cup_{m=1}^{M} s_m^{i)}$).
- $s_{feasible}^{i)}$ feasible schedule generated from $s^{i)}$ by applying a "feasibility restore mechanism".
- $SL^{i)}$ list with the m current requests in $s^{i)}$) sorted by a priority rule (or several concatenated priority rules)
- $sl_j^{i)}$: request in position j of the list $SL^{i)}$.
- $sl_{j,feasible}^{i)}$: request in position j of the list $SL^{i)}$ after rebuilt it (if necessary) to try to make it feasible (if possible).
- $pa_{tk}^{i)}$: price of arrival slot in coordination time interval t in airport k for the iteration $i)$.
- $pd_{tk}^{i)}$: price of departure slot in coordination time interval t in airport k for the iteration $i)$.
- $\delta a_{tmkf}^{i)}$: auxiliary variable, set to 1 if the arrival of the flight movement f in airport $k \in K$ in combinatorial request m is assigned to interval t in iteration $i)$.
- $\delta d_{tmkf}^{i)}$: auxiliary variable, set to 1 if the departure of the flight movement f in airport $k \in K$ in combinatorial request m is assigned to interval t in iteration $i)$.
- $P_m^{i)}\left(s_m^{i)}\right)$: payment if the requested slots in $s_m^{i)}$ will be allocated to the combinatorial request m. It is function of the current prices ($pa_{tk}^{i)}$, $pd_{tk}^{i)}$) of the requested slots:

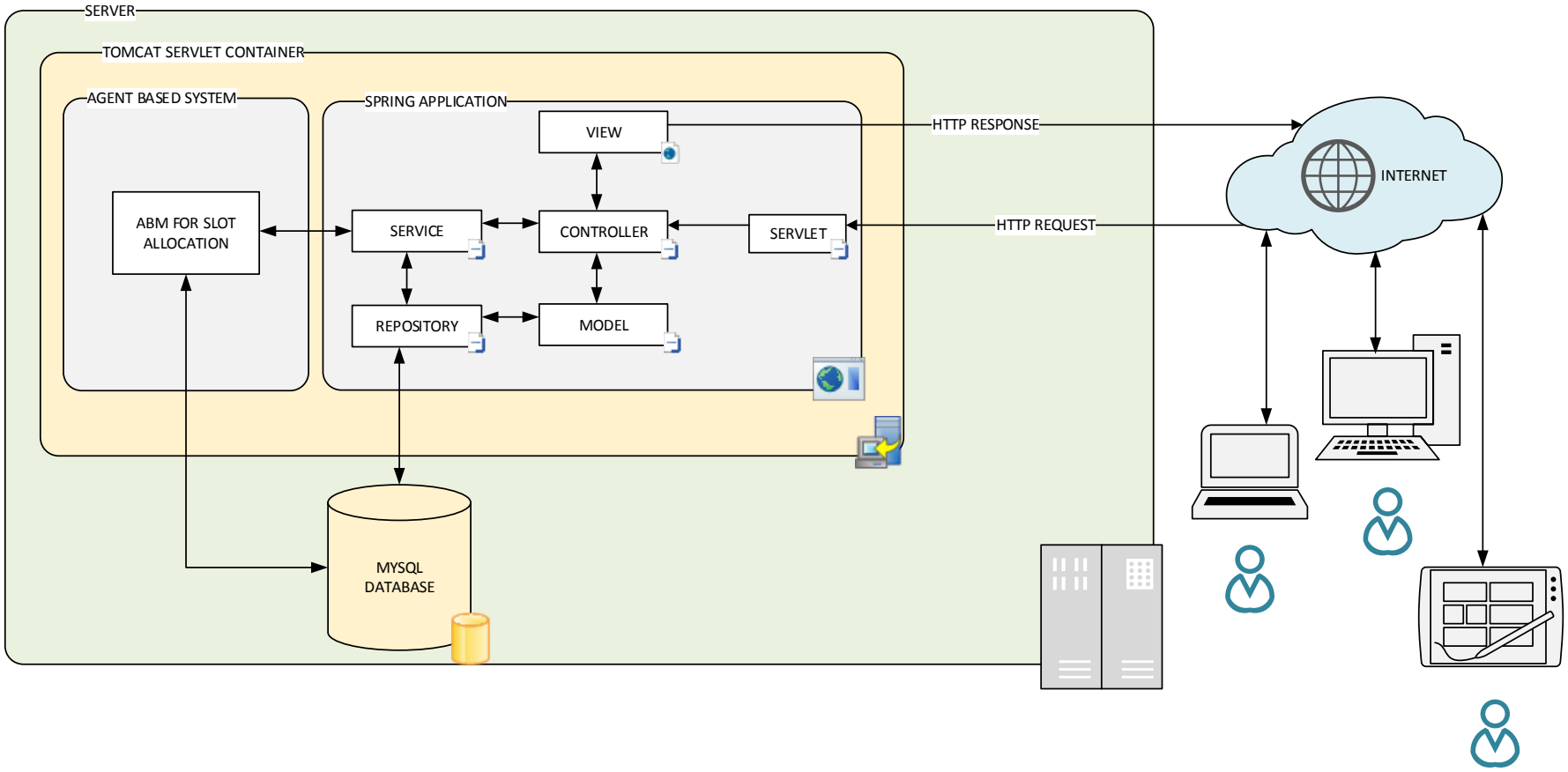
$$P_m^{i)}\left(s_m^{i)}\right) = \sum_{k=1}^{K}\sum_{t=0}^{T-1}\left(pa_{tk}^{i)} \cdot \sum_{f=1}^{f_{mk}} \delta a_{tmkf}^{i)} + pd_{t,k}^{i)} \cdot \sum_{f=1}^{f_{mk}} \delta d_{tkf}^{i)}\right)$$

Mathematical specification

In a situation where the slots allocated violate the airport's capacity constraints, it shall be applied the following feasibility restoration heuristic with priority rules:

Step 0.	Initialization: The *coordinator* (auctioneer) checks whether the current slot allocation at certain airport, $s^{i)}(= \bigcup_{m=1}^{M} s_m^{i)})$, is feasible according to its capacity constraints or not. -If so, it makes $s_{feasible}^{i)} = s^{i)}$ and moves to *Step 6*. -Otherwise, it makes the set of winner request $s_{feasible}^{i)} = \emptyset$ and moves to *Step 1*.
Step 1.	The *coordinator* produces a sorted list $SL^{i)}$ with the m current request $s_m^{i)}$ at the end of auction $i)$ using the following priority rules: - Requests with biggest payments in the auction are prioritised. - Requests containing more slots are prioritised. - Random prioritisation. To break ties between multiple requests, several criteria can be concatenated. The random prioritisation shall break any tie.
Step 2.	The *coordinator* takes the first request $sl_1^{i)}$ in $SL^{i)}$ and checks whether the selected request $sl_1^{i)}$ can be scheduled in the slots currently requested without violating any capacity constraint or not. -If so, the slot allocation of the request $sl_1^{i)}$ is feasible ($sl_{1,feasible}^{i)} = sl_1^{i)}$). Go to *Step 5*. -If not, the request $sl_1^{i)}$ must be "feasibility restored". Go to *Step 3*.
Step 3.	The auctioneer will modify $sl_1^{i)}$ to try to make it feasible, trying to keep it as close to the originally requested slots (in $s^{i)}$) as it is possible considering the accomplishment of the capacity constraints. The displacement of the request shall respect the existing temporal space (coordination intervals) between slots in the original request (this implicitly considers the values for $s_{m,k,f}$ and $e_{m,k\to k',f}$, actually unknown by the coordinator). Summarising, the *coordinator* displaces performs a direct displacement of the original request certain number of coordination time intervals forward or backwards in time. There are two possibilities: - No feasible modification can be found for the request, the current slot request is discarded. The coordinator updates $SL^{i)}$ deleting the request $sl_1^{i)}$. Go to *Step 2*. - A feasible modification $sl_{1,feasible}^{i)}$ for $sl_1^{i)}$ request is found. Go to *Step 4*.
Step 4.	The *coordinator* asks to the airline whether it accepts the modified request $sl_{1,feasible}^{i)}$ with a payment $P_{1,feasible}^{i)}\left(sl_{1,feasible}^{i)}\right)$ evaluated at current auction $i)$ prices $(pa_{tk}^{i)},\ pd_{tk}^{i)})$. Two possibilities: - The airline accepts. Go to *Step 5*. - The airline does not accept the modification. The request is discarded. The *coordinator* updates $SL^{i)}$ deleting the request $sl_1^{i)}$. Go to *Step 2*.
Step 5.	The *coordinator* aggregates the selected request $sl_{1,feasible}^{i)}$ to the set of winner requests ($s_{feasible}^{i)} = s_{feasible}^{i)} \cup s_{1,feasible}^{i)}$), and updates $SL^{i)}$ deleting the request $sl_1^{i)}$. The allocated slots count for the compliance of capacity constraints in the following steps. The auctioneer checks if the following stop criteria is satisfied: every request has been processed ($SL^{i)} = \emptyset$) or the current status of accomplishment of the airport's capacity constraints prevents to allocate more slots. Two possibilities: - The stop criteria is met. Go to *Step 6*. - Otherwise, go to *Step 2* and repeat the loop.
Step 6.	The coordinator announces the set final slot allocations $s_{feasible}^{i)}$.

Annex VI. System architecture



www.access-sesar.eu