# An Agent-Based Auction Model for the Analysis of the Introduction of Competition in ATM

J. Torres, D. Toribio, R. Marcos, O. G. Cantú Ros and R.Herranz
Nommon Solutions & Technologies
Madrid, Spain
javier.torres@nommon.es

***Abstract*—The provision of air traffic services has for a long time been a national monopoly. The introduction of competition in the ATM sector has been proposed as a means to incentivize the adoption of new technology and more efficient strategies. In this paper, we analyze a possible mechanism for the introduction of competition in the ATM market consisting in the tendering of licenses to operate en-route air navigation services within certain geographical areas. The license tendering process is simulated by means of an agent-based model. The model is used to investigate the potential impact of the proposed institutional design and how the outcomes of the process are influenced by different parameters of the tenders, such the frequency of the auctions and the order in which the different areas are auctioned.**

***Keywords-air navigation services, license tendering, agent-based modelling.***

## I. Introduction

The Single European Sky (SES) initiative aims to restructure the European airspace, create additional capacity and increase the overall efficiency of the ATM system, so that the European ATM system can cope with sustained air traffic growth under safe, cost-efficient and environmentally friendly conditions. The European Commission has set ambitious goals for the SES to be reached by 2020, including a 3-fold increase in airspace capacity and a cost reduction of at least 50% in the provision of ATM services.

In this context, the question of how to provide the appropriate organizational structures, institutions and incentives for new operational concepts and technologies to yield the expected results stands high on the policy agenda. The introduction of competition has been proposed as a means to provide the right incentives for the realization of the high-level objectives of the SES, through the speed up of the innovation cycle and the fostering of more efficient operations. On the other hand, competition does not prevent every market failure (e.g., negative externalities) and, depending on market conditions, liberalization can also have undesired outcomes, such as the emergence of oligopolies or monopolies. The SESAR 2020 Exploratory Research project COMPAIR (http://www.compair-project.eu/), in which the present work is framed, investigates how to introduce competitive incentives in ATM so as to best contribute to achieving the European policy objectives for aviation.

Economic research on ATM is not abundant. Most economic studies which have analyzed economic drivers for ATM performance have focused on price as the main instrument for change ([1]). Only A few studies have investigated different institutional approaches that have an impact on the industrial structure of the ATM sector, such as the study by Baumgartner and Finger [2] and the SESAR WPE projects ACCHANGE [3] and ACCESS [4] that studied how institutional change could affect ATM performance. In line with these studies, COMPAIR has analyzed four different institutional designs.

One of the institutional designs proposed by COMPAIR is the tendering of licenses to provide air traffic services within certain geographical areas. Auctions and tendering processes have been widely studied using game theoretical approaches [5]. However, due to the strong assumptions behind game theory, such as agents' rationality, these models may fail to capture the complexity of the interactions between the system constituents. Additionally, the equilibrium seeking nature of game theory models limits their usefulness to study the dynamics of this type of institutional setting, in which the assignation of the different geographical areas to the distinct ANSPs is not necessarily expected to reach equilibrium.

In recent years, agent-based modelling (ABM) [6] has been recognized as a powerful tool for simulating and analyzing complex bidding environments. In this paper, we present the agent-based model developed by the COMPAIR project to simulate the tendering of ATC licenses with the aim of providing insights into what type of auction design would produce the most efficient outcomes. The rest of the paper is organized as follows: Section II describes the general logic of the simulation model and the main modelling assumptions; Section III describes the case study used to investigate the proposed tendering mechanism and the scenarios analyzed; Section IV discusses the main results of the simulations; and Section V concludes and discusses future research directions.

## II. Description Of The Model

### A. Overall Description

The model simulates the tendering of licenses to operate en-route air traffic services in specific geographical areas and for a certain period of time by employing the agent-based modelling paradigms. It comprises three main elements:

1. Geographical context, which provides the environment for the agents to operate in.
2. Agents. Three types of agents are considered: (i) the regulator, (ii) the ANSPs, and (iii) the airlines.
3. Exogenous variables, which represent arbitrary external conditions that affect the model but are not affected by it. The exogenous variables considered in the model are fuel prices and passenger demand.

The simulation consists of two stages:

- The first stage simulates the tendering process, where the ANSPs compete for the control of different geographical areas. In this stage, only the regulator and the ANSPs participate. Each ANSP submits a certain unit rate per service unit (p*€/km, where p is the weight factor of the aircrafts) that will be the maximum unit rate applicable in that area during the license period if that ANSP wins the tender. Contract conditions include the minimal capacity the ANSPs have to provide during the license period and the maximum market share an ANSP can handle in order to avoid monopolistic behaviors.
- The second stage simulates how agents evolve between auctions. In this stage also airlines participate. They react to the ANSPs decisions by choosing different routes according with the air navigation charges in each geographical zone. Charges are adjusted every given period of time until the license period is over.

Once the license period expires, the tendering process is repeated, which can lead to contract renewal for the incumbent provider or to a new provider. The simulation finishes when the temporal horizon is reached.

## B. *Modelling Assumptions*

The main modeling assumptions are the following:

- ATCOs may monitor not only flights in their current charging zone but also flights in any of the charging zones controlled by the ANSP they are working at.
- At the beginning of the simulation, ATCOs working at a specific charging zone ("legacy ATCOs") will always work at the ANSP controlling their original area and maintain their labor agreement throughout the simulation (until retirement).
- New ATCOs (non-legacy ATCOs), who are hired throughout the simulation, will have the same cost regardless of their nationality and will be employed by the same ANSP during all the simulation, unless they are dismissed. The rationale behind the unitary cost is that a consequence of hiring ATCOs from any country in the EU and allowing them to work remotely is that they will have the same cost, either because they may be all hired from the same country or because the liberalization and free competition between ANSPs of all countries will lead to costs' homogenization
- When hiring new ATCOs, there is an initial extra cost due to training.
- When dismissing new ATCOs, there is an extra cost due to dismissal costs.
- Under same technology conditions, different ATCOs are assumed to be equally efficient regardless their experience, and ANSP they work at. The difference of productivity between ANSPs is a parameter of each ANSPs simulating its level of technology adoption, and not an ATCO's parameter.
- If an ANSP's capital becomes negative, the ANSP goes into bankruptcy.
- New ANSPs are not allowed to enter the market.
- An average plane size, load factor and operational cost per kilometer are considered for all flights regardless of the origin-destination pair.

## C. *Geographical Context*

The geographical context provides the environment for the agents to operate in. It is composed by: (i) a set of charging zones that the ANSPs compete to control; (ii) a group of airports representing the main destinations within the charging zones; and (iii) a collection of routes per origin-destination pair defining the possible paths the airlines can fly.

## D. *Agents*

### 1) *Agents' description*

#### a) *Regulator*

The role of the regulator is to provide and store the public data created throughout the simulation (e.g., air navigation charges for each charging zone), announce the auction parameters and select the winners of the auctions.

#### b) *ANSPs*

The ANSP agents are the main agents of the simulation. They make decisions to achieve their objectives according to their internal parameters, their competitors and the environment. They are modeled as profit-maximizers, but objective functions could be easily implemented, such as revenue maximization or cost minimization.

The parameters that define an ANSP are: (i) charging zones they control; (ii) human resources (number of ATCOs); (iii) financial capital. The capital available by ANSPs to invest either in hiring ATCOs, improving their technology level or to pay the cost of dismissing staff; (iv) bidding strategy. It defines the learning method ANSPs will employ to characterize their competitors' behavior and calculate their bids and; (v) technology level.

#### c) *Airlines*

The airline agents, which represent the different airlines that fly daily over the European sky, are assumed to be cost minimizers. Their objective is to meet the total expected demand at the minimum possible cost. Operating costs other than fuel cost and fees are modeled as an internal parameter of the agent.

*2) Agents' interaction rules*

The sequence of agents' decisions and actions follows the schemes included in Figure 1, Figure 2 and Figure 3.

*a) Auctioning Process*

The auctioning process is depicted in Figure 2.

The regulator announces the auction parameters, which include the minimum capacity that the winning ANSPs shall provide in each area, calculated based on the OD demand forecast and assuming that the distribution of flights per route in each OD pair will be the same as the distribution of the last periods, and allocates the auction areas to the winning bidders.

The ANSPs submit a bid corresponding to the maximum charge that would be applied to the auctioned zone.

To submit the bid the ANSPs take the following actions:

1. Calculate their total resulting market share in case of winning the auction and evaluate if this accomplishes the condition of the maximum market share allowed.
2. Determine the minimum profitability they want to achieve. This lies between a minimum and a maximum value set to 7% and 12% of the total cost of controlling the network respectively, and grows proportionally with an adaptive factor, α, calculated as:

$$\alpha = \frac{M\,share_{ANSP}}{max\;M\,share} + \frac{demand_{ANSP}}{max\_demand_{ANSP}} \in [0,2], \text{ and}$$

$$min\;profitability = min_{value} + \alpha * \frac{\max\_value - \min\_value}{2}$$

With $M\,share_{ANSP}$ the ANSP's current market share, $max\;M\,share$ the maximum allowed market share, $demand_{ANSP}$ the expected demand for the zones currently managed by the ANSP, and $max\_demand_{ANSP}$ the maximum demand the ANSP can control with the current resources.

3. Estimate in an iterative process the best bid charge by multiplying the current charge by a bid factor, ranging from 0.5 to 1.5 in steps of 0.001. For each bid factor they: (a) estimate the resources needed according to their technology level and the expected number of flights, calculated based on the passenger demand forecast and the average plane size and occupancy rate; (b) estimate the total profit, as the difference between the expected income and cost, and the profitability, dividing the expected profit by the expected cost; (c) obtain the probability of beating their competitors. This is calculated with one of the following learning methods: Friedman [7] and Gates [8] which characterize the behavior of all their competitors and estimate the probability of winning the auction accordingly, and Fine [9] which only characterizes the pattern of the winning bids of previous auctions, (d) calculate the auction expected profit, defined as the product of the expected profit by the probability of winning the auction.
4. Finally submits the bid that maximizes the auction expected profit.

Once the regulator has allocated the areas to the winning ANSPs, they decide the amount of capital to invest during the following license period in order to upgrade their technology level, which is used as the main driver of the productivity of the ANSPs. This amount corresponds to a percentage (an 80% in this case) of the expected profit of the starting license period, regardless the characteristics and size of the controlled areas. The monetary impact of technology upgrade has been obtained from the figures of the Master Plan 2012 [10].

*b) Evolutive Process*

The sequence of agents' decisions and actions follows the scheme included in Figure 3.

The regulator ensures that the ANSPs provide the required capacity and do not select a charge greater than the one they offered in their bid and stores the public information that will be used by the ANSPs and the airlines in future steps.

The ANSPs examine different combination of charges within the areas they control and, for each combination of charges, take the following actions: (i) estimate the resources needed according to the demand forecast, the charge of their competitors and the distance that each route flies over each charging zone; and (ii) calculate the expected profit of the combination of areas they control during the following time step. Based on this information, they select the combination of charges that maximizes their expected profit.

The airlines' goal is minimizing its costs while meeting passenger demand. Once the ANSPs publish the charges of each charging zone, airlines select the route of each flight according to the cost of the route with a probability

$$P(r = R) = \frac{e^{utility_R}}{\sum_r e^{utility_r}} \;,$$

with r running over all possible routes for a given pair,

$$utility_R = K_{OD}/cost_R \text{ and}$$

$K_{OD}$ a constant with a different value for each OD pair.

## *E. Exogenous Variables*

The exogenous variables considered in the model are the fuel price and the passenger demand.

Passenger demand defines a number of passengers at each simulation step and for each origin-destination pair. Forecasted passenger demand is known by all the agents. The regulator uses it to establish the minimum capacity that the ANSPs have to provide in each zone. The ANSPs employ it to establish the unit charge for each time step. Finally, the airlines use this information to set the number of flights per origin-destination pair. Actual demand is calculated by the model as a deviation from the forecasted data, by adding a stochastic noise at each step. As a result, actual demand may differ from the forecast, and the forecast values for the following simulation steps are modified accordingly (see Figure 4).

Similar to passenger demand, there is a forecasted fuel price profile known by the airlines and the ANSPs. As for travel demand, the actual fuel price is calculated as a deviation from the forecast, by adding a stochastic noise to the forecasted value at each simulation step and adapting the forecast values for the following simulation steps.

The purpose of including a stochastic component is to test the ability of the different agents to adapt to changing circumstances in the presence of uncertainty.

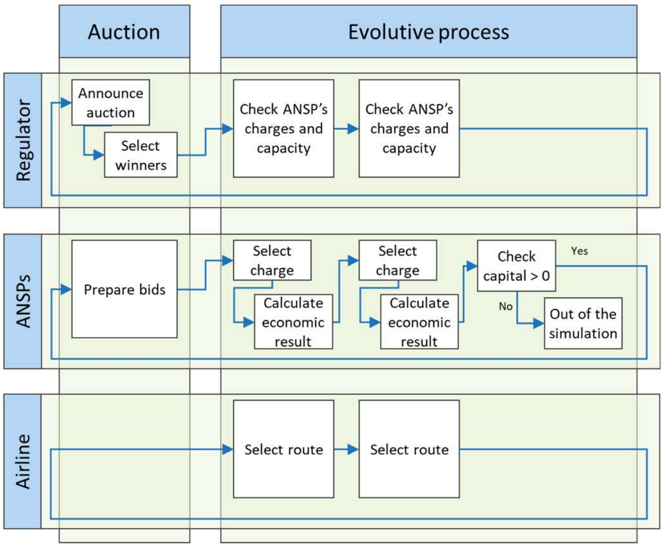



Figure 1. Agents' behaviour rules

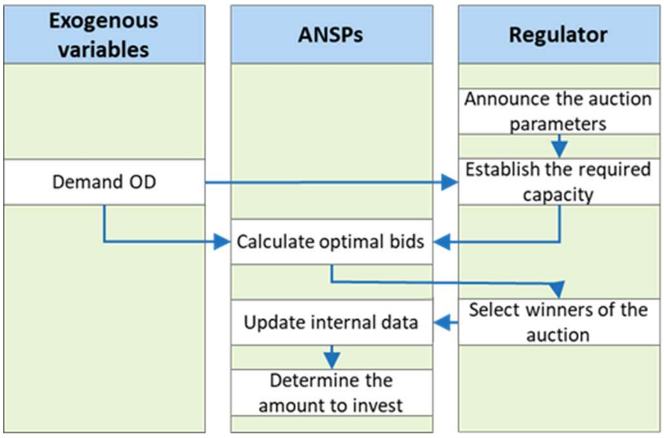



Figure 2. Auctioning process. Agents' interactions

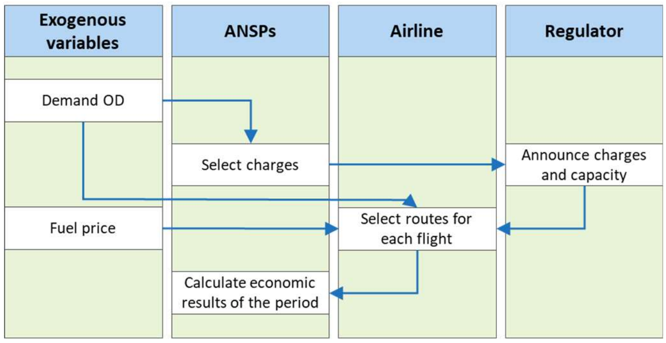



Figure 3. Evolutive process. Agents' interactions

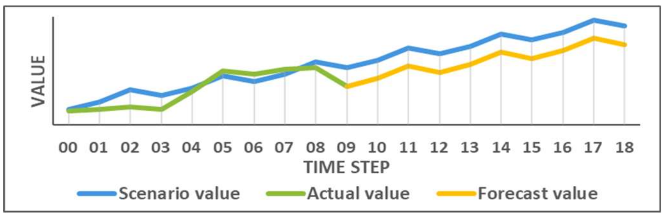



Figure 4. Example of scenario, actual and forecasted value

## III. Data Sources And Case Study

### A. *General Parameters*

The proposed case study simulates the liberalization of the ATM market in Western Europe in 2015. The model has been initialized with the ANSPs' and airlines' data of 2014 year ended, summarized in Table 1 and Table 2 respectively.

The network analyzed, presented in Figure 5, includes eleven charging zones, eleven ANSPs and a set of possible routes between the thirteen airports considered in the simulation.

All airlines are modeled as an average airline by means of a single agent that meets all the demand. The data used to model the airline have been obtained from the annual financial reports of the main European airlines ([11], [12], [13], [14]). These data are presented in Table 2

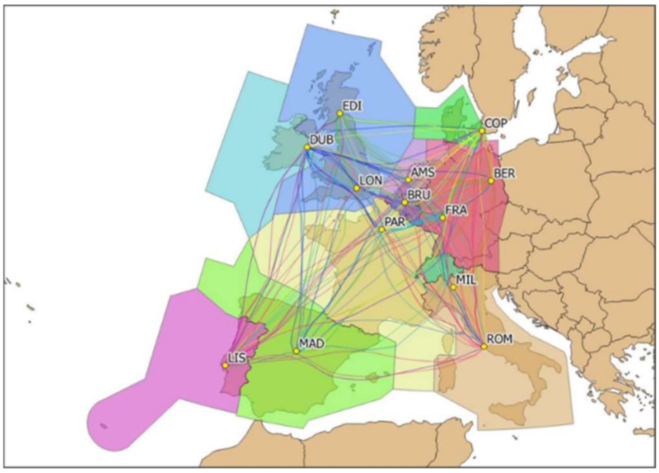



Figure 5. Geographical scope and network of the case study

TABLE 1 ANSPs' EN-ROUTE DATA

| **ANSP** | **Staff cost (M €)** | **Non-staff operating cost (M €)** | **Other cost (M €)** | **IFR flight-km (000 km)** | **Average charge per km (€)** |
|---|---|---|---|---|---|
| Belgocontrol | 98.8 | 15,1 | 20.7 | 173,363 | 0.96 |
| DFS | 629.6 | 81.0 | 185.8 | 1,103,672 | 0.73 |
| DSNA | 641.8 | 190.0 | 127.0 | 1,542,050 | 0.78 |
| ENAIRE | 393.8 | 67.8 | 142.5 | 882,223 | 0.79 |
| ENAV | 295.5 | 113.7 | 146.9 | 711,039 | 0.83 |
| IAA | 52.9 | 20.7 | 14.8 | 214,828 | 0.55 |
| LVNL | 126.8 | 22.4 | 11.2 | 209,564 | 0.58 |
| NATS | 319.6 | 87.2 | 188.7 | 798,501 | 0.98 |
| NAV | 72.7 | 8.7 | 7.9 | 240,379 | 0.49 |
| NAVIAIR | 48.6 | 12.1 | 19.3 | 138,344 | 0.66 |
| Skyguide | 141.1 | 13.8 | 33.8 | 208,425 | 0.70 |

TABLE 2 AIRLINE DATA

| Airline | CASK total (€ cent) | CASK fees (€ cent) | CASK fuel (€ cent) | CASK other (€ cent) |
|---|---|---|---|---|
| EasyJet | 5.91 | 0.46 | 1.87 | 3.58 |
| Air France | 6.93 | 0.53 | 1.9 | 4.50 |
| Lufthansa | 8.8 | 1.47 | 1.89 | 5.44 |
| British Airways | 7.49 | 0.55 | 2.45 | 4.49 |
| **Average Airline** | **Output of the model** | **Output of the model** | **2.05** | **4.50** |

The data of the ANSPs have been obtained from the 2014 ATM Cost-Effectiveness Benchmarking Report [15]. These data have also been employed to calibrate the number of flights per origin-destination pair since the network is a simplification of reality and the number of flights has to be adapted to this network. Given the distribution of flights per OD pair, and the distance that each route flies over the charging zones, the number of flights per OD pair has been adjusted to obtain the actual demand of 2014 in every country.

The ANSPs simulated are Belgocontrol (Belgium), DFS (Germany), DSNA (France), ENAIRE (Spain), ENAV (Italy), IAA (Ireland), LVNL (Netherland), NATS (United Kingdom), NAV (Portugal), NAVIAIR (Denmark) and Skyguide (Switzerland), which provide air traffic services to around 60.5% of the total IFR flight-km in Europe. The figures of the Maastricht Upper Airspace Control Centre (MUAC) have been split into these countries and allocated to the corresponding ANSPs. The parameters of each ANSP are summarized in Table 1.

Passenger demand forecast has been obtained from EUROCONTROL's report "Challenges of Growth 2013" [16]. We have employed the data of the most likely scenario, the so-called "Regulated growth", which considers that the demand will grow 1.8% annually. Since the data provided for demand growth is aggregated at a regional level, demand growth had to be assumed homogenous among the EU countries. According to this scenario, the demand in 2050 would double the current demand.

## B. Scenarios

To analyze the influence of different auction parameters, several scenarios are built:

### 1) Market Share

The market share is calculated as the flight-km controlled by an ANSP divided by the total number of flight-km in the network. A maximum allowed market share is set to avoid the appearance of monopolistic or oligopolistic behaviors.

We analyze two different values of the maximum allowed market share: 40% and 60%. These values ensure the existence of at least 3 and 2 ANSPs, respectively.

### 2) Auctioning Order

In the simulation, the charging zones are auctioned individually and sequentially in the same time step. Thus, the order in which they are auctioned has an influence on the results (e.g., due to the limit imposed on the market share, it may occur that an ANSP cannot bid for some area if it has been previously allocated other areas).

We analyze the outcome of auctioning the areas in different orders according to the size of each national market:

- Ascending: Denmark, Belgium, Switzerland, Netherlands, Ireland, Portugal, Italy, United Kingdom, Spain, Germany, France.
- Descending: France, Germany, Spain, United Kingdom, Italy, Portugal, Ireland, Netherland, Switzerland, Belgium, Denmark.
- Mixed: Denmark, France, Belgium, Germany, Switzerland, Spain, Netherlands, United Kingdom, Ireland, Italy, Portugal.

### 3) License duration

The license duration determines the frequency of the auctions. The largest the license duration, the fewest auctions will take place within the simulation. If only few auctions occur, ANSPs do not have enough data to properly analyze the bidding behavior of their competitors and adapt their own behavior.

Two different values of the license duration are analyzed: 5 and 10 years.

Since the aim of this paper is to analyze the impact of the different auction parameters and not to compare the effectiveness of the bidding strategies, all ANSPs employed the same one (Gates model) for all scenarios described before.

# IV. ANALYSIS OF RESULTS

## A. Market Share

The maximum market share parameter has a very significant influence on the outcome of the tendering, especially on the distribution of charging zones being controlled by each ANSP.

As expected, for a maximum market share of 40%, we find more market competition between ANSPs than with a maximum market share of 60% (see Figure 6). In the first case, two big ANSPs control almost 40% of the market each and two or three ANSPs control minor areas (Figure 6.a). On the contrary, when the market share is set to 60%, there is a dominant ANSP whose market share tends to increase in every tendering process controlling more than 50% of the market at the end of the period of study. Moreover, in this scenario the whole market is controlled by fewer ANSPs (Figure 6.b).

The maximum market share does not seem to affect the trend followed by the evolution of the charges and the total number of ATCOs in the network (Figure 7 and Figure 8). In the case of a market share of 40%, the average charge obtained in 2050 is 38 €cents/km, 10% greater than in the case of a maximum market share of 60%, and the total number of ATCOs is 15% higher.

This is due to the investment in technology made by ANSPs. In the 60%-scenario the total profit is divided by a fewer number of ANSPs, hence they have more money to invest in technology and increase their efficiency to a greater extent than in the 40%-scenario.

In spite of these advantages, a maximum market share of 60% could lead to an oligopoly in which the market is dominated by two ANSPs which control over 90% of the market, with a tendency to increase this percentage. The emergence of oligopolies is an undesired outcome of the liberalization of any market. Thus, a maximum market share over 50%, although presenting some minor benefits in the short-term period, could lead to oligopolistic behaviors in the long-term. When limiting the market share to 40%, the market is consolidated into four ANSPs out of eleven, which seems a more appropriate number of players to ensure real competition.

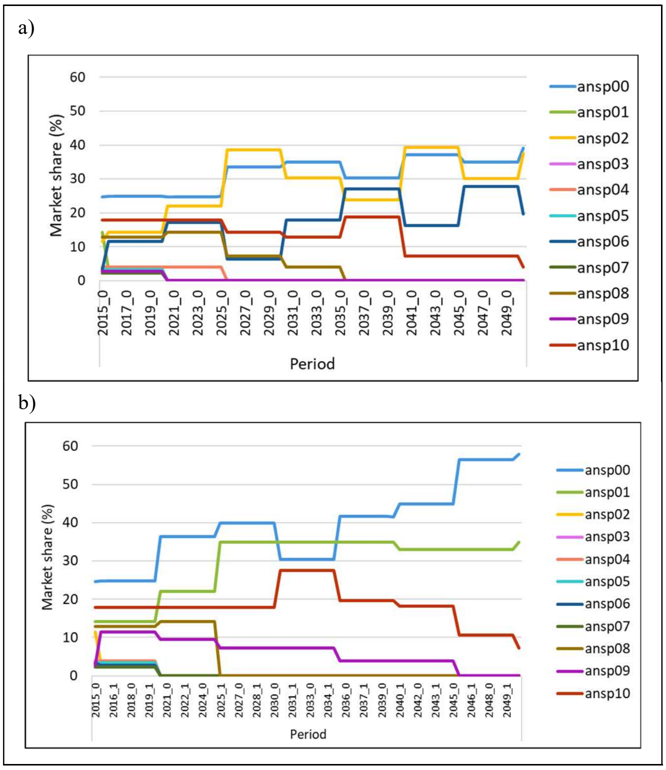



Figure 6. ANSPs' market share: a) maximum market share set to 40%; b) maximum market share set to 60%

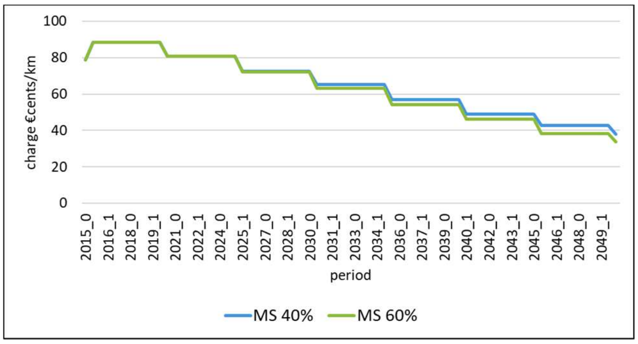



Figure 7. Average network charge

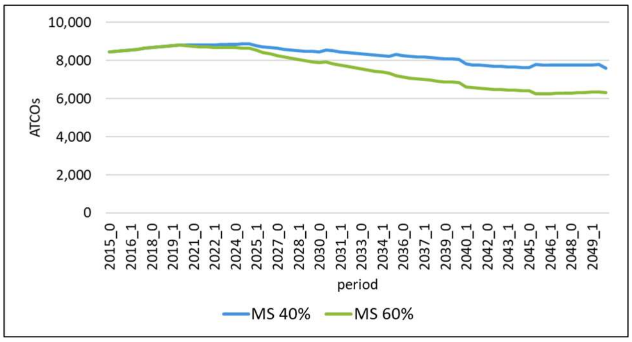



Figure 8. Total number of ATCOs

## *B. Auctioning Order*

The auctioning order influences locally the charging prices resulting from the tendering but it has a minor impact on the global outcome.

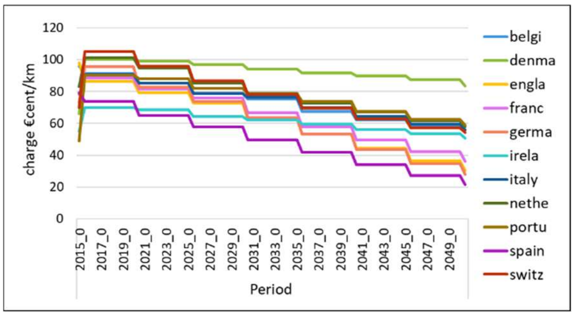
Figure 9 presents the resulting charges obtained in each country for different auctioning orders in a scenario with a maximum market share of 40%. It may seem that, in the "descending" order (Figure 9.a), the total fees the airlines will have to pay are greater than in the other scenarios. However, the average network charge paid by airlines (considering the flight demand over each country) is quite similar for the three options (Figure 9.d), The reason is that in the "descending" scenario the biggest countries are auctioned first and the ANSPs behave more aggressively offering lower charges. Finally, when the smaller areas are auctioned, the dominant ANSPs have ensured a high market share for the following license period, in some cases close to the maximum market share, and they are not allowed to participate or they are not interested in tendering for these areas unless they could obtain a great profit. Then, the less efficient ANSPs have a chance to be allocated one of the small countries, offering a higher charge. The same effect occurs with the latest zones to be auctioned in the "ascending" (Figure 9.b) and the "mixed" order (Figure 9.c), but to a minor extent. In the three scenarios, it is observed that the last zone to be auctioned gets the highest charges (Denmark in the "descending" scenario, France in the "ascending" scenario and Portugal in the "mix" scenario), with differences in charges specially marked in the "descending" one.

Comparing Figure 9.a, Figure 9.b and Figure 9.c, we can conclude that the mixed ordering produces more homogeneous charges between the different countries.

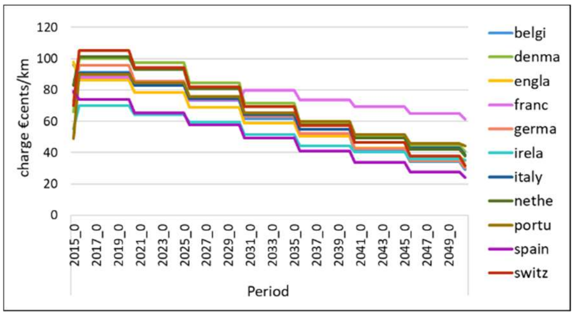
## *C. License Duration*

The last parameter we evaluate is the frequency of auctions. Two scenarios have been evaluated: (i) a 5-year license duration; and (ii) a 10-year license duration. For both scenarios, the maximum allowed market share was set to 40% and the auctioning order to "mixed". The results are depicted in Figure 10 and Figure 11.

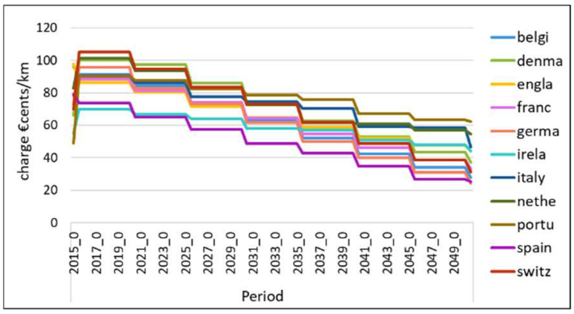
The charges in both scenarios tend to decrease at the same rate. Also, the rates in 2050 are almost the same for both scenarios (Figure 10). Since the charges fall at the same rate, the average bid factor of the winning bids lowers as the frequency of auctions decreases.



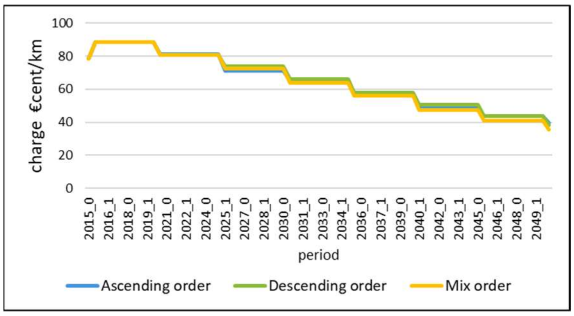

a) Auctioning order set to Descending




b) Auctioning order set to Ascending




c) Auctioning order set to Mixed




d) Average charges

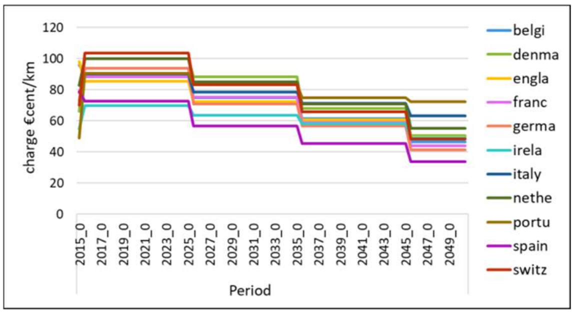
Figure 9. Influence of the auctioning order in the charges for a maximum market share of 40%

There is a considerable difference in the resulting market share of the ANSPs for the two scenarios. In the 10-year scenario (Figure 11.a) the market remains stable from 2035 to 2050. Five ANSPs control the whole market, having 4 of them a market share over 15%, which suggests a very competitive scenario. In the 5-year scenario, the ownership of the charging zones switches after every tendering process (Figure 11.b). Two dominant ANSPs control the 40% of the market each, the maximum they are allowed to. The remaining zones are shared by two minor ANSPs. These results would suggest that a license duration of 10 years would lead to a more stable and competitive market.

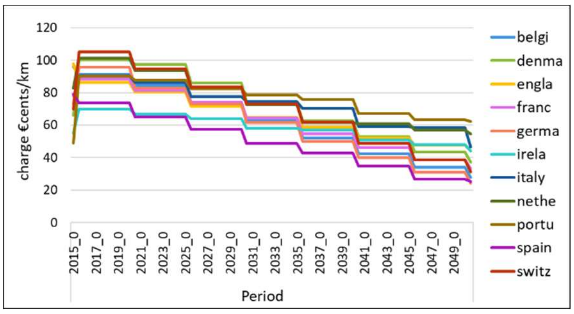
## *D. General Outcome*

An important outcome of all the scenarios tested is that, in general, the ANSPs which control the biggest charging zones at the beginning of the simulation (the ANSPs with the highest market share on the first period) perform better in the long term, since they have more resources to invest at the beginning of the simulation. On the contrary, the smallest ANSPs usually disappear between the second and the fifth auction as they are not competitive enough against the dominant ANSPs.

It is also noticeable that when there is a dominant ANSP that controls a big part of the market, due to its investment capacity and the economies of scale, e.g., reallocating ATCOs to different charging zones according to the labor requirements, both the total number of ATCOs and the average charge are a bit lower than when the market is controlled by more ANSPs. However, what seems a clear benefit in the short/medium-term may lead to the emergence of an oligopoly in the long-term.

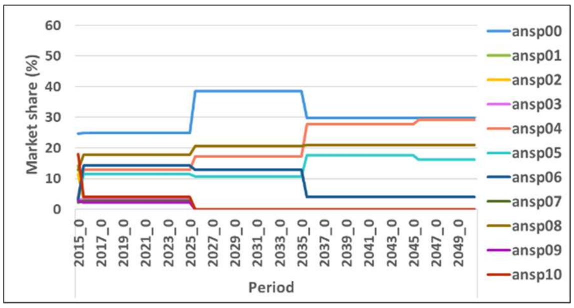



a) License's duration set to 10 years

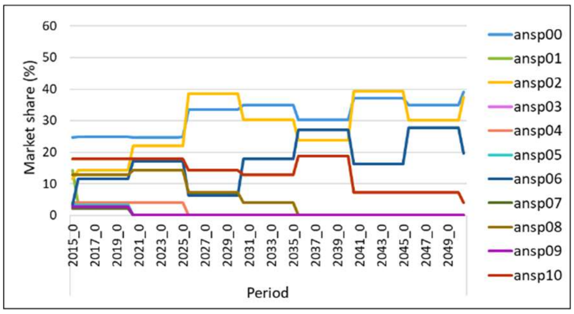



b) License's duration set to 5 years

Figure 10. Influence of the licenses duration in the charges for a maximum market share of 40% and "Mix" auctioning order




a) License's duration set to 10 years




b) License's duration set to 5 years

Figure 11. Influence of the licenses duration in the ANSPs' market share for a maximum market set of 40% and "Mix" auctioning order

## V. Summary And Future Research

In this paper, we have presented an agent-based model designed to investigate the impact of a hypothetical tendering of licenses to operate air traffic services within Europe. The model simulates the behavior of a group of ANSPs which compete for the control of different charging zones to maximize their profit and a set of airlines that aim to meet the passenger demand while minimizing their costs. The ANSPs have been endowed with learning and adaptive behaviors, i.e. ANSPs use historical data to devise a strategy and they have the capability to adapt their strategy to respond to new conditions, aimed to calculate the bids according to their actual status and the previous bids of their competitors.

We have illustrated the potential of the proposed approach to analyze the dynamics and the final outcome of the process by exploring the influence of different auctioning parameters, namely the frequency of auctions, the maximum market share established by the regulator, and the order in which the charging zones are auctioned. The results allow us to derive useful insights about the criteria to be taken into account for such type of institutional framework.

Several model enhancements are currently being implemented and will be used for future studies:

- Different investment strategies could be implemented so that the ANSPs select the amount to invest on technology depending on their status and the environment conditions.
- More complex and realistic scenarios will be modeled, such as scenarios considering uncertainty in the exogenous variables. This will allow us to study the adaptability of the ANSPs to changing and unexpected conditions with different degrees of volatility, and to measure the ability of different institutional designs to provide the required level of resilience and adaptability.
- More airline agents empowered with learning capabilities will be included, in order to have a more realistic representation of airline behavior. This will allow us to take into account the cost of congestion and the daily distribution of flights.
- ANSP behaviors other than profit maximization will be implemented, e.g. to explore the potential impact of anticompetitive practices.
- The possibility of ties and merges between ANSPs will be explored.
- The simulation scenario will be extended to the whole ECAC area.
- Finally, simulations will be conducted to compare the outcome obtained with different type of auctions. In particular, we will compare the single-unit auction described in this paper with a combinatorial auction in which all the areas are tendered at the same time and ANSPs bid for different combination of charging zones, in order to investigate the trade-offs between the economies of scale offered by the combinatorial auction versus the presumably more effective learning process enabled by a sequence of single-unit auctions.

## Acknowledgment

The project leading to these results has received funding from the SESAR Joint Undertaking under grant agreement No 699249 under European Union's Horizon 2020 research and innovation program.

## References

[1] Jovanovic, Tosic, Cangalovic and Stanojevic, "Anticipatory modulation of air navigation charges to balance the use of airspace network capacities",. Transportation Research Part E, 84-99, 2014.

[2] Baumgartner and Finger, "The single European sky gridlock: a difficult 10-year reform process". Utilities Policy, 289-301, 2014

[3] http://tmleuven.be/project/acchange/home.htm

[4] https://www.access-sesar.eu/

[5] A. Hailu and S. Schilizzi, "Learning in a 'Basket of Crabs': An Agent-based computational model of repeated conservation auctions," Nonlinear Dynamics and Heterogeneous Interacting Agents, pp. 27-39, 2005.

[6] C. M. Macal and M. J. North, "Tutorial on agent-based modelling and simulation". Journal of simulation, vol.4.3, pp. 151-162, 2010.

[7] L. Friedman, "A competitive-bidding strategy," Operations research, vol. 4, nº 1, pp. 104-112, 1956.

[8] M. Gates, "Bidding strategies and probabilities," Journal of the Construction Division, vol. 93, nº 1, pp. 75-110, 1967.

[9] S. Asgari and A.Shafaat, "Simulating Construction Bidding Using Agent-Based Modelling".

[10] European ATM Master Plan Edition 2, October 2012.

[11] AirFrance, KLM. Annual Financial Report 2014.

[12] EasyJet. Annual reports and accounts 2014.

[13] Lufthansa Group. Annual Report 2014.

[14] British Airways Plc. Annual Report and Accounts. Year ended 31 December 2014.

[15] ATM Cost-Effectiveness (ACE) 2014 Benchmarking Report.

[16] Challenges of Growth 2013. Task 7: European Air Traffic in 2050.