Application of Agent-Based Computational Economics to Strategic Slot Allocation

State-of-the-art and Future Challenges

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Contents

Executive summary

The current European Regulation for airport slot allocation, which retains and develops the principles of the IATA slot allocation process, has been proven insufficient to cope with the gap between capacity and traffic, and there is evidence that the design of the current process is neither consistent with an economically efficient use of capacity nor with the facilitation of fair competition at congested airports. Both issues are acknowledged by the European Commission in the proposal for a new slot regulation included in the Airport package adopted on 1st December 2011. Market-based mechanisms are expected to provide the right economic incentives to favour a more efficient use of the available capacity, as well as higher flexibility for airlines to adapt their slot portfolio to their business objectives and planning constraints; but market mechanisms also imply a number of risks, ranging from the potentially negative impact on airline operating costs and the resulting network effects, to market imperfections, exercise of market power, or market failures. Moreover, the effects of a specific mechanism can vary depending on the implementation details. There is therefore a need for a comprehensive assessment of the impact of different market designs on network performance and on ATM stakeholders.

ACCESS (Application of Agent-Based Computational Economics to Strategic Slot Allocation) is a research project within SESAR WPE Long Term and Innovative Research which addresses the problem of airport slot allocation from the perspective of complex adaptive systems. Due to the complexity of the combinatorial assignment problems underlying primary slot auctioning and secondary slot trading, agent-based computational economics provides a particularly suitable framework to undertake a rigorous and formal study of different alternatives for market design, allowing the modelling and exploration of features — such as bounded rationality, evolutionary behaviour or asymmetry of information — that are not properly captured by classical approaches from economics and operations research.

The project pursues the following objectives:

- perform a quantitative analysis of the improvement margin of the current airport slot allocation system;
- review different market-based mechanisms used in other sectors, and analyse whether they could be suitable to tackle the problem of strategic airport capacity allocation;
- formalise the mechanisms retained as a result of the previous analysis;
- develop a theoretical framework for the evaluation of slot allocation mechanisms, with the aim to assess their impact on network performance and the costs and benefits for the involved stakeholders;
- develop a software tool implementing the theoretical framework and allowing the testing of the proposed market-based mechanisms. The tool will encompass a simulation model and a data analysis module allowing the interaction with the simulation results and facilitating their interpretation;
- provide an assessment of the proposed market-based mechanisms at European level, identifying the main levers and barriers for their implementation;
- propose a roadmap for the implementation of the most beneficial solutions.

In addition to developing new modelling approaches which are expected to deliver its full potential in the medium-to-long term, ACCESS will feed the SESAR mainstream programme and the European Slot Regulation with valuable results in the short term. The lack of consistency between slots and flight plans is one of the main reasons for air traffic delay at the busiest European airports. ACCESS will model the influence of airport slot allocation on the performance indicators defined by the Single European Sky and SESAR, looking at strategic airport capacity allocation in the context of the European network. The departure and arrival slots at coordinated airports constitute an early definition of the 4D trajectory, determining the solution space for the subsequent trajectory negotiation: improving the consistency between airport slots and flight plans is thus a key condition to meet the strategic SESAR objective of achieving a full integration of airports into the ATM network.

The ACCESS Consortium is composed by Nommon (Project Coordinator), ALG-Europraxis, the Social Systems Engineering Centre (INSISOC) of the University of Valladolid, and the University of Trieste.

1. The problem of airport slot allocation

1.1 Managing airport congestion

The continuous growth in air transport along the last decades has put increased pressure on airport capacity. According to the long-term forecast produced by EUROCONTROL in December 2010 [EUR10], taking into account currently planned infrastructure, 5%-19% of the demand for air transport (0.7-5.0 million flights) will not be accommodated in 2030 due to a shortage of capacity at European airports. Although the long-term forecast prepared in 2010 will be updated downwards by about 6% (or equivalently back by 2 years) in the most likely scenario due to the recent economic and traffic downturn [EUR12], there is a general consensus that airport congestion is one of the key challenges facing European aviation, as acknowledged by the European Commission in several recent communications [Com11a, Com11b].

Congestion imposes large costs on airlines and passengers [Bal10, Coo10]. The construction of new airports or new runways has a look-ahead time of 5 to 10 years, and it can often be complicated or even impossible, due to cost, environmental impact, land availability, or political reasons. Consequently, improvements in the management of capacity and demand have lately been the subject of much attention. The approaches to congestion management can be classified according to their time horizon. Strategic planning includes measures with a planning horizon of 6 months to 2 years, which can vary from strategic flow management actions (e.g., routing schemes), to demand management policies for the assignment of airport resources. The latter can be either purely administrative, as it is the case for the strategic assignment of airport slots; purely economic, such as congestion pricing; or hybrid [Mad06]. Medium-term and pre-tactical planning include measures such as the seasonal Network plan elaborated in front of a new season with pre-defined demand and capacity scenarios. Finally, tactical adjustments are short term solutions adopted on the day of the flight, essentially through ground holdings (i.e., delays imposed by ATFM slot) and re-routings. A detailed overview of the different congestion mitigation mechanisms developed by the air transport industry can be found in [Bar12].

1.2 Demand management policies

The ACCESS project will focus on demand management policies for the allocation of airport resources. Even though several studies carried out along the last decade have shown that administrative slot controls lead to inefficiencies by hindering competition and creating entry barriers [Dot01, NER04], slot control and schedule coordination have been so far the dominant approach in Europe. The European Commission's 2011 White Paper on Transport [Com11a] acknowledged the need to revise the Slot Regulation to favour more efficient use of airport capacity, opening the door to the introduction of market-based mechanisms. A comprehensive assessment of such mechanisms should help develop a better understanding of the economic value of each slot, evaluate the effect of different possible market designs on network performance, and analyse the potential impact on competition and competitiveness of operators.

2. The need for an improved slot allocation system

2.1 The current slot allocation system

The IATA slot allocation process [IAT12] is the access control mechanism employed by most of the busiest airports in the world outside the US. For EU airports, slot allocation is regulated by Regulation 95/93 [Cou93] and its respective amendments [Eur02, Eur03, Eur04, Eur09], which retain and develop the principles of the IATA system. Within the framework of this Regulation, each Member State conducts a capacity assessment in each airport of its jurisdiction. If there is a significant capacity shortfall, the Member State may designate an airport as ''coordinated'', i.e., "an airport where, in order to land or take off, it is necessary for an air carrier or any other aircraft operator to have been allocated a slot by a coordinator, with the exception of State flights, emergency landings and humanitarian flights". A slot is ''the permission given to a carrier to use the full range of airport infrastructure necessary to operate at a slot-controlled airport on a specific date and time for the purpose of landing or take-off''. Alternatively, the Regulation allows a Member State to designate an airport as ''schedule facilitated'', i.e., "an airport where there is potential for congestion at certain periods of the day, week or year which is amenable to resolution by voluntary cooperation between air carriers and where a schedules facilitator has been appointed to facilitate the operations of air carriers operating services or intending to operate services at that airport".

The designation of a coordinated airport is followed by the appointment of a slot coordinator, which should act in a transparent, independent, and non-discriminating manner. The coordinator determines the ''declared airport capacity'' and the associated ''coordination parameters'', such as the coordination time interval. The declared capacity specifies the number of slots (i.e., scheduled movements) available for allocation at an airport per unit of time. The coordination time interval is the unit of time (e.g., 5 min, 15 min, 60 min) used as the basis for capacity determination and slot allocation.

Slots are allocated in series. A series of slots is a set of five or more slots requested for the same time of day and the same day of the week during a specific time period. The input to the slot allocation process is a list of requests, each specifying an arrival or departure time (possibly both), a start and end date, and the days of the week on which the request will operate. The declared capacity is rationed by the coordinator according to three general priority classes: (i) requests with historical rights, (ii) requests with new entrant status, and (iii) remaining requests. Within each class, additional sub-criteria may apply [IAT12]. The objective is to allocate requests as close as possible to their requested time. First, each request with historical rights (the so-called ''grandfather rights'') is allocated to the corresponding slot, provided that the slot was used over 80% of the time during the previous equivalent season ("80-20" or ''use-it-or-lose-it'' rule)[1]. Half of the remaining slots are reserved for new entrants, i.e., airlines with limited presence at the airport on a specific day, slot, and route. Unassigned requests are assigned to the remaining slots, and all the allocated slots become ''grandfathered'' for the next season. The coordinator must recognise claims for

[1] The "use it or lose it" rule was temporarily suspended (so-called waiver) following the events of 11 September 2001, and on the occasion of the Iraq war and the SARS epidemic in 2003. Due to the intensity of the economic crisis and its impact on air carriers, the "use it or lose it" rule was again suspended temporarily in 2009. Regulation (EC) No 545/2009, adopted on 18 June 2009, allowed air carriers to keep the same slots for the summer season of 2010 as attributed to them for the summer season of 2009.

‘‘grandfather rights’’, monitor the usage of slots, and withdraw slots that have not been sufficiently or efficiently used according to the ‘‘use-it-or-lose-it’’ rule.

The slots allocated to an airline may be exchanged for slots held by another airline, providing airlines with some flexibility to match slots and routes. Under the current Regulation, the transfer of slots is permitted only on a one-for-one, non-monetary basis. This often involves the exchange of a valuable slot for a “junk slot” late in the evening or in the early afternoon, which is not particularly useful. Following the trade, the “junk slot” is returned to the pool. In practice, a market in airport slots (in the form of secondary trading) has been in operation at UK airports for some time, as the Commission recognised in 2008 [Com08], and there are well-known cases of slots at London Heathrow that have been traded for high prices.

Slot allocation is performed twice per year, for the summer and winter scheduling periods. The main instrument of the IATA system is the organisation of biannual, international scheduling conferences with the participation of slot coordinators, airport representatives, and airline delegates. Before these meetings, airlines submit their (confidential) slot requests to the coordinator. The coordinator applies then the rules and priority classes to prepare a draft proposal compiling airlines’ preferences. During the conference, initial allocation proposals are discussed to establish a consensus on the allocation of slots for the next scheduling season. The after conference activity involves bilateral negotiations among airlines with the aim to establish mutually beneficial exchanges of slots. The airport coordinator is responsible for confirming the operational feasibility and legal validity of slot exchanges.

There are currently 89 fully coordinated airports in countries where the Slot Regulation applies (the EEA plus Switzerland). Of these airports, 62 are coordinated year-round, and 27 are coordinated seasonally [Com11b].

2.2 Shortcomings and limitations of the current system

During the last decade, there has been a significant research effort focused on the development of optimisation models implementing the IATA slot allocation regime and its version of the EU regulation [Zog11]. However, the existing EU/IATA rules have been proven insufficient to cope with the gap between capacity and traffic, and several studies commissioned by the EC [NER04, Mot06, Ste11a] have concluded that the efficient use of airport capacity in Europe is hindered by a number of problems:

- the transparency of slot information could be improved;
- in some countries, the system could be interpreted to limit the independence of the coordinator;
- slot allocation is not consistent with an economically efficient use of capacity. A major drawback is the loss of efficiency due to grandfather rights: the use-it-or-lose-it rule induces airlines to underutilise capacity to retain the slots, prevent the entry of lower cost competitors and avoid losing pricing power [Har07], which produces strong entrance barriers for potential competitors [Dot01, Mal03, Sta98];
- a significant percentage of the allocated slots are not used. At some airports, the late return of slots and overbidding reduce the capacity that can be effectively used;
- the mobility of slots is low. The fact that the transfer of slots is permitted only in a limited number of cases narrows the ability of airlines to adapt their slots to their scheduling needs;

- to compete effectively with the dominant carrier at a given airport, a new entrant needs to build up a sustainable slot portfolio. Under the current rules, airlines quickly fall outside the definition of 'new entrant', which obstructs the growth of efficient competition;
- there is a lack of consistency between slots and flight plans.

To address these problems, as part of the Airport package adopted on 1st December 2011, the EC launched a proposal aimed at improving the use of scarce capacity at busy airports [Com11b]. The new proposal:

- increases the level of transparency on slots transactions;
- defines stricter criteria for the independence of the coordinators with respect to interested parties;
- asks for enhanced cooperation between the coordinators (e.g., for the development of common slot allocation software);
- opens the door to the future creation of a European coordinator responsible for slot allocation at all EU airports;
- allows airlines to trade slots with each other at airports anywhere in the EU in a transparent way;
- reforms the rules designed to help new entrants access the market at congested airports;
- tightens the rules to demonstrate that airlines have used their slots sufficiently during the season; and
- advocates the integration of slot allocation with the Single European Sky initiative, by associating the European Network Manager with the slot allocation process.

3. Market-based mechanisms for slot allocation

An efficient mechanism should allocate slots to those airlines which value them the most. The introduction of market-based mechanisms for the use of airport slots is expected to bring appropriate incentives that will positively influence the behaviour of players in the market (airlines) so that the available scarce capacity is used by those airlines able to make best economic use of it. Different consultations launched by the EC in 2010, published in [Ste11b], show that airlines are in general satisfied with the functioning of the current Regulation, while airports and, to a lesser extent, slot coordinators and Member States, see more need for change.

Several authors have investigated the opportunity of implementing auction mechanisms for managing slots, following the current practice at some US airports [Cra07, Fuk10, Kle96, Mal03, Sen03, Sta98, Ver10]. Madas and Zografos [MZ06] make an interesting qualitative analysis of different possible approaches, characterised by an increasing level of differentiation with respect to the current mechanism. At one extreme, grandfather rights are combined with administrative coordination. At the other extreme, grandfather rights are entirely abandoned and the slot allocation is based on decentralised auctions. The intermediate strategies are characterised by different combinations of grandfather rights, central coordination and free market.

Recent studies have tackled primary slot auctioning and secondary slot trading, delivering promising results. Castelli, Pellegrini and Pesenti [Cas12] carry out a quantitative analysis of the economic impact of grandfather rights by comparing airlines' costs when these rights are either enforced or not. The study proposes a primary slot allocation mechanism based on an integer programming model and performs experimental tests on simulated air traffic demand over a portion of Europe. The results show that the system disutility (i.e., the sum of the costs of the individual airlines due to the imbalance between demand and capacity) is higher when grandfather rights are present, and suggest that it is possible to remove grandfather rights without significantly penalising the airlines which own them, by introducing compensation mechanisms for transferring the disutility of the system to each airline and redistributing among airlines the surplus deriving from the elimination of grandfather rights. In [Pel12a], the same authors propose a formalisation of secondary slot trading based on an individual rational and budget balanced combinatorial slot exchange. The suggested market mechanism considers en-route sector capacities, showing that solutions that appear optimal when neglecting airspace capacity can be infeasible when it is taken into account. This result is aligned with the EC objective of improving the consistency between airport and ATFM slots to allow the saving of costly delays on the day of operations. The study concludes that the proposed combinatorial exchange offers a significant reduction of airline costs compared to current practice.

4. A computational economics approach

4.1 Auction theory

Auction theory is an applied branch of economics which deals with how people act in auction markets and investigates the properties of those markets [Kle99]. There are many possible designs (or sets of rules) for an auction, but they always satisfy two conditions: the auction may be used to sell any item, and the outcome of the auction does not depend on the identity of the bidders. Most auctions have the feature that participants submit bids. Standard auctions require that the winner of the auction is the participant with the highest bid. A non-standard auction does not require this (e.g., a lottery).

Auctions can be classified according to different criteria. Combinatorial auctions are particularly interesting for the slot allocation problem. A combinatorial auction is a multi-item auction in which bidders can bid for any combinations or packages of the auctioned items, instead of bidding only for individual items. Complementary items are those goods whose joint acquisition brings more utility for the buyer than in a separate way. Combinatorial auctions solve a problem that buyers may suffer in sequential multi-item auctions, known as “exposure risk” [Rot98], which is materialised when a bidder cannot win in all the auctions of items which are complementary, thus not being able to extract the expected utility of other assets already acquired. The main problem of combinatorial auctions is the determination of the combination of bids that maximises auctioneer’s benefit. The problem admits a linear programming formulation, but it is an NP-hard problem [Rot98], so finding a solution is neither easy nor quick. Its resolution has been faced from several points of view, applying approaches such as genetic algorithms, search taboo, backtracking, simulated annealing, etc.

Auctions have been studied from different perspectives [Ham19, Coa98, Rot07, Sho10]. Typical issues studied by auction theorists include the efficiency of a given auction design, optimal and equilibrium bidding strategies, and revenue comparison. Auction theory is also used to inform the design of real-world auctions. The applications cover a variety of domains, such as manufacturing process control, resource management, privatisation of public sector companies, or allocation of the electromagnetic spectrum, among others.

4.2 Agent-based modelling and simulation

Agent-based modelling (ABM) has achieved great influence in the last years in fields like sociology [Con97, Gil95, Gil99, Sul00, Lop04], political science [Axe97, Joh99], economy [Art97, Tes02, Lop04], biology [Res97, Bau09], anthropology [Wol03, Lan03] or natural resources management and ecology [Bou04, Har04, Lan03, Gal09]. Generally, an agent-based model is a computer model consisting of a number of software objects, the agents, interacting within a virtual environment [Fer99]. The agents, which often have a one-to-one correspondence with the real world actors [Lop01], have a degree of autonomy, react to and act on their environment and on other agents, and have goals that they aim to satisfy. ABM allows the observation of the emergent behaviour arising from agents’ interactions in a bottom-up process [Mos99], combining formality and rigour while minimising disadvantages such as strong hypothesis dependency [Lop04]. Despite the fact

that agents are assigned an individual behaviour pattern, the resulting social behaviour is seldom a simple and predictable consequence of the individual patterns. An example is Schelling's segregation model [Sch78], considered by many as the first agent-based model, which shows how decisions made at the microscopic level evolve up to recognisable patterns at the macroscopic level [You98]. Recent papers in outstanding economics and scientific journals [Eco10, Far09] claim that economists should adopt ABM as the best way to improve their models.

Agent-based modelling constitutes a particularly suitable approach to represent and simulate a combinatorial auction market [Fue11, Her00, Pos08, Pos09]. Examples of this approach are applications for firms and governmental agencies [Abd05, Rot05]; radio spectrum auctions [Ton09, Hof10]; electricity markets [Nic01]; or management of multi-project environments [Ara10]. In the case of airport slot allocation, the complexity of the combinatorial assignment problems underlying primary slot auctioning and secondary slot trading makes agent-based computational economics a suitable framework to undertake a rigorous and formal study of different alternatives for market design, allowing the exploration of features — such as bounded rationality, evolutionary behaviour or asymmetry of information — that are not properly captured by classical approaches from economics and operations research.

5. The ACCESS project

ACCESS (www.access-sesar.eu) is a research project within SESAR WPE Long Term and Innovative Research which addresses the problem of airport slot allocation from the perspective of complex adaptive systems. The project is conducted by a Consortium composed by Nommon (Project Coordinator), ALG-Europraxis, the Social Systems Engineering Centre of the University of Valladolid (INSISOC), and the University of Trieste, and is co-financed by EUROCONTROL acting on behalf of the SESAR Joint Undertaking and the European Union.

5.1 Project objectives

ACCESS pursues the following objectives:

1. perform a quantitative analysis of the improvement margin of the current airport slot allocation system;
2. review different market-based mechanisms used in other sectors, and analyse whether they could be suitable to tackle the problem of strategic airport capacity allocation;
3. formalise the mechanisms retained as a result of the previous analysis;
4. develop a theoretical framework for the evaluation of slot allocation mechanisms, with the aim to assess their impact on network performance and the costs and benefits for the involved stakeholders;
5. develop a software tool implementing the theoretical framework and allowing the testing of the proposed market-based mechanisms. The tool will encompass a simulation model and a data analysis module allowing the interaction with the simulation results and facilitating their interpretation;
6. provide an assessment of the proposed market-based mechanisms at European level, identifying the main levers and barriers for their implementation; and
7. propose a roadmap for the implementation of the most beneficial solutions.

5.2 Approach

The project will first analyse the current mechanisms for slot allocation in Europe, identifying the inefficiencies and the potential for improvement, and will characterise the roles, responsibilities, goals and strategies of the different actors involved, with a view to understand their expectations and devise the right incentives to influence their behaviour. The design principles and the practical experience with auction-based mechanisms in other sectors will be reviewed, which will serve as a basis to formalise different possible designs for market approaches to airport slot allocation, as well as to define a set of criteria against which such market designs should be evaluated and compared. We will then build a test environment which will include a stylised model of the air transport network and the behavioural models of the agents playing a relevant role in slot allocation: a pilot model will be first developed, with a view to elucidate the cause-effect relationships between the model elements and the emerging patterns; then, a complete model of the ECAC area will be built. We will also develop visual analytics tools with the purpose of facilitating the interaction between the modellers and the ATM stakeholders in a way which can better support policy discussions. Finally, ACCESS will define a number of relevant scenarios and will make use of the newly developed models

and tools to assess the impact of the proposed market-based mechanisms. The pilot model will be used to undertake a theoretical study of the full range of proposed solutions, which will lead to the selection of a reduced number of market designs whose implementation and impact at European level will be evaluated by making use of the ECAC simulation model. ACCESS will also aim at facilitating the uptake of those mechanisms identified as beneficial, by working in close collaboration with academic, industrial and regulatory bodies to outline an implementation roadmap.

5.3 Target outcomes and expected impact

Scientific impact

ACCESS aims at providing an enhanced understanding of different effects which, as of today, are not totally well understood:

- Grandfather rights have led legacy airlines to optimise the exploitation of their most valuable slots. The removal of grandfather rights may lead to the displacement of the flight departure and/or arrival times. ACCESS will help grasp the implications of this effect for airline revenues and costs.
- The problem of how a slot allocation mechanism affects the whole schedule planning, from airline routes and flight schedules to pricing decisions, is expected to have unmanageable size and a level of complexity beyond the state-of-the-art [CPP12]. ACCESS will provide a first exploratory analysis of this problem at a simplified level.
- ACCESS will model the interdependence of slots at the origin and destination airports. So far most studies have considered airports as independent of one another, neglecting that, for each flight, an airline needs a feasible combination of slots at the origin and destination airports. ACCESS will extend the work of the few studies that have formally considered this interdependence, such as the pioneering work of Rassenti at al. [Ras82] and, more recently, the work of Pellegrini at al. [Pel12b].
- The modelling work done so far considers fixed cost functions and aircraft speeds. ACCESS will analyse the effect of relaxing these two assumptions.
- Current models assume perfectly rational behaviour of the agents. ACCESS will relax this assumption to explore the effects of bounded rationality and evolutionary behaviour.
- ACCESS will deliver a first assessment of the role of the Network manager and the so-called network airports, which will enter into the problem of slot allocation as a result of the recent EC proposal for the revision of slot allocation rules [Com11b].
- The theoretical framework developed by ACCESS can also contribute to advance in the resolution of other ATM problems, e.g. a similar modelling approach could be applied to ATFM slot trading.

Impact on policy, technology and competitiveness

ACCESS will support the development of the EU Slot Regulation by informing the design of mechanisms to improve the use of airport capacity. Regulation 691/2010 will impose demanding capacity and efficiency targets to Airport Operators, requiring new strategies for the allocation of limited resources. Due to the complexity of the problem, characterised by many interacting actors with different business models, time

scales and constraints, extensive simulations and analysis are needed to produce sufficient evidence supporting the choice of a specific mechanism and ensuring the buy-in of all the stakeholders. ACCESS will contribute to this goal, not only by supporting the implementation of the regulation, but also by setting the basis for the development of decision support tools for airlines to choose their optimal strategies.

Relevance to SESAR

The 4D Business Trajectory is one of the main pillars of the SESAR Concept of Operations. According to the SESAR ConOps, the Business Trajectory evolves out of a collaborative layered planning process involving all the stakeholders concerned and is embodied in three main instantiations [Ses12]:

- the Business Development Trajectory (BDT), which is internally defined by the Airspace Users based on their business strategy and the resulting flight programme for each season. This in turn is constrained by the availability of aircraft and flight crew resources;
- the Shared Business Trajectory (SBT), which is published by the Airspace User prior to flight execution for collaborative planning purposes. The refinement of the SBT is an iterative process. The final form of the SBT becomes the Reference Business Trajectory;
- the Reference Business Trajectory (RBT), which is the latest instantiation of the SBT. It is the trajectory that the Airspace User agrees to fly and that the ANSP and Airport agree to facilitate.

The mechanisms implementing the 'collaborative layered planning process' for the elaboration of the SBT mentioned in [Ses07] have not yet been defined by the SESAR projects under the current development phase. However, it is foreseen that Collaborative Decision Making (CDM) principles will apply to the entire trajectory management process to plan, agree, update and revise the Business Trajectory [Ses12].

The departure and arrival slots at coordinated airports constitute an early definition of the 4D trajectory. Therefore they are fundamental elements in the process of trajectory management since its earliest stage. The request for slots from Airspace Users is directly dependent on their business strategy, and the successive phases of airport slot assignment through IATA conferences already constitute a collaborative planning process involving Airspace Users and Airport Operators during the strategic phase of flight planning. The collaborative planning advocated by SESAR is likely to rely on an integrated system for Airspace Users to request and exchange slots, in accordance with the European Regulation. Hence, it is of the utmost importance to ensure the consistency of the principles and rules for slot assignment with the trajectory management concept and its overall objectives of efficiency, flexibility, equity and participation. On the one hand, the Airspace Users ask for an ATM system that is able to flexibly adapt to the actual conditions of the network and to the availability of flight resources, which implies that the trajectory should be available for modifications and amendments to optimally respond to user needs. On the other hand, a certain level of stability and predictability is required to allow the appropriate planning and synchronisation of different stakeholders' schedules, which will require limitations on the changes in the trajectory.

These needs call for a structured and well-designed process for trajectory management, whose first stage lies exactly at the assignment of airport slots. Since airport slots determine the solution space for the subsequent trajectory negotiation process, the design of the airport slot allocation mechanisms is of paramount importance for SESAR, in particular for the strategic objective of achieving a full integration of

airports into the ATM network and ensuring a seamless process through CDM. The improved consistency between airport slots and flight plans is one of the operational improvements included in the SESAR Master Plan (OI DCB-0301), yet the research effort of the SESAR mainstream programme is focused on the mechanisms to be put in place from the short term planning phase up to the execution phase to accommodate the demand. The subject of airport slots is only directly addressed in the Airport Detailed Operational Description [Ses11], as a responsibility of Airport Operators:

- during the long-term planning phase, to prepare allocation of airport slots;
- during all phases of flights, to facilitate operations by negotiating the allocation of airport slots with the Airspace Users and defining the airport slot allocation plan;
- during flight execution, to improve consistency on a daily basis by monitoring the utilisation of airport slots by the Airspace Users and ensuring convergence between airport slots and ATFM slots.

Apart from this mention, airport slot assignment is a side issue in SESAR operational and system projects. ACCESS is intended to fill this gap, thus contributing to the achievement of two of the strategic business needs of SESAR: Airport Integration and Throughput (i.e., a full integration of airports into the ATM network), and Network Collaborative Management.

Annex I. References

[Abd05] Abdulkadi roğlu, A.; P. A. Pathak; A. E. Roth; T. Sönmez (2005). The Boston Public School Match. The American Economic Review, Vol. 95, No. 2, pp. 368-371.

[ACI04] ACI-Europe (2004). Study on the use of airport capacity. Airports Council International, Brussels, Belgium.

[Ara10] Arauzo, A; J. Pajares; A. López-Paredes (2010). Simulating the dynamic scheduling of project portfolios. Simulation Modelling Practice and Theory, 18 (10); pp. 1428-1441.

[Art97] Arthur, W.B.; S. N. Durlauf; D. A. Lane (1997). The Economy as an Evolving Complex System II. Arthur, W. B.; S. N. Durlauf & D.A. Lane (Eds.), s.l., Proceedings Volume XXVII, Santa Fe Institute Studies in the Science of Complexity, Reading, MA. Addison-Wesley, Advanced Book Program.

[Axe97] Axelrod, R. (1997). The Complexity of Cooperation: Agent-Based Models of Competition and Collaboration. Anderson, P.W. et al. (Eds.), s.l., Princeton University Press.

[Bal10] Ball M.O.; C. Barnhart; M. Dresner; M. Hansen; K. Neels; A. Odoni; E. Peterson; L. Sherry; A. Trani; B. Zou. Total delay impact study: a comprehensive assessment of the costs and impacts of flight delay in the United States. Federal Aviation Administration.

[Bar12] Barnhart, C.; D. Fearing D.; A. Odoni; V. Vaze (2012). Demand and capacity management in air transportation. Euro Journal of Transportation and Logistics, Vol. 1, No 1-2 (2012), 135-155, DOI: 10.1007/s13676-012-0006-9.

[Bau09] Bauer, A. L.; C. A. A. Beauchemin; A. S. Perelson (2009). Agent-based modeling of host–pathogen systems: the successes and challenges. Information Sciences, Vol. 179, No. 10, April, pp. 1379-1389.

[Bou04] Bousquet, F.; C. Le Page (2004). Multi-agent simulations and ecosystem management: a review. Ecological Modelling, Vol. 176, No 3-4, pp 313-332. Elsevier.

[Cas12] Castelli, L.; P. Pellegrini; R. Pesenti (2012). Airport slot allocation in Europe: economic efficiency and fairness. International Journal of Revenue Management, Vol. 6, No. 1-2, pp. 28-44.

[Cra07] Cramton, P.; M. Ball; L. Ausubel; F. Berardino; G. Donohue; M. Hansen; K. Hoffman (2007). Market-Based Alternatives for Managing Congestion at New York's LaGuardia Airport. Optimal Use of Scarce Airport Capacity. Proceedings of AirNeth Annual Conference. The Hague, Netherlands.

[Coa98] Coase, R. (1998). The New Institutional Economics. American Economic Review, 88(2), pp. 72-74.

[Com08] Commission of the European Communities (2008). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. On the application of Regulation (EEC) No 95/93 on common rules for the allocation of slots at Community airports, as amended. COM(2008) 227 final. Brussels, Belgium.

[Com11a] Commission of the European Communities (2011). White Paper: Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system. COM(2011) 144 final. Brussels, Belgium.

[Com11b] Commission of the European Communities (2011). Airport package. Proposal for a Regulation of the European Parliament and the Council on common rules for the allocation of slots at European Union airports. COM(2011) 827 final. Brussels, Belgium.

[Con97] Conte, R. (1997). Simulating Social Phenomena. Conte, R.; R. Hegselmann; P. Terna (Eds.), s.l., Springer.

[Coo10] Cook, A.; G. Tanner (2010). European airline delay cost reference values. Final Report for EUROCONTROL Performance Review Unit, EUROCONTROL, Brussels, Belgium.

[Cou93] Council of the European Communities (1993). European Council Regulation (EEC) No. 95/93 of January 1993 on Common Rules for the Allocation of Slots at Community Airports. Official Journal of the European Union, L 14, 22.01.1993, p.1. Brussels, Belgium.

[Dot01] Dot Econ Ltd. (2001). Auctioning airport slots: a report for HM treasury and the department of the environment, transport and the regions. London, UK.

[Eur02] European Parliament and Council of the European Union (2002). Regulation (EC) No 894/2002 of the European Parliament and of the Council of 27 May 2002 amending Council Regulation (EEC) No 95/93 on common rules for the allocation of slots at Community airports. Official Journal of the European Union, L 142, 31.5.2002, p.3. Brussels, Belgium.

[Eur03] European Parliament and Council of the European Union (2003). Regulation (EC) No 1554/2003 of the European Parliament and of the Council of 22 July 2003 amending Council Regulation (EEC) No 95/93 on common rules for the allocation of slots at Community airports. Official Journal of the European Union, L 221, 4.9.2003, p.1. Brussels, Belgium.

[Eur04] European Parliament and Council of the European Union (2004). Regulation (EC) No 793/2004 of the European Parliament and of the Council of 21 April 2004 amending Council Regulation (EEC) No 95/93 on common rules for the allocation of slots at Community airports. Official Journal of the European Union, L 138, 30.4.2004, p.50. Brussels, Belgium.

[Eur09] European Parliament and Council of the European Union (2004). Regulation (EC) No 595/2009 of the European Parliament and of the Council of 18 June 2009 amending Council Regulation (EEC) No 95/93 on common rules for the allocation of slots at Community airports. Official Journal of the European Union, L 167, 29.6.2009, p.24. Brussels, Belgium.

[Eur10] European Commission (2010). Conclusions of the stakeholders' hearing on the possible revision of the Slot Regulation. 29/11/2010.

[EUR10] EUROCONTROL (2010). Long-Term Forecast: IFR Flight Movements 2010-2030. Brussels, Belgium.

[EUR12] EUROCONTROL (2012). Challenges of Growth 2013. Task 1: on the use of the 20-year forecast published in 2010. Brussels, Belgium.

[Far09] Farmer, J.D.; D. Foley (2009). The economy needs agent-based modelling. Nature, Vol. 460, No. 7256, pp. 685-686.

[Fer99] Ferber, J. (1999). Multi-Agent Systems: An Introduction to Distributed Artificial Intelligence. Addison-Wesley Longman Publishing Co., Inc., Boston, MA.

[Fue11] Fuentes-Fernández, R.; J. M. Galán; S. Hassan; F. A. Villafáñez (2011). Metamodelling for Agent-Based Modelling: An Application for Posted Pricing Institutions. Studies in Informatics and Control, Vol. 20, No. 1, pp. 55-66.

[Fuk10] Fukui, H. (2010). An empirical analysis of slot trading in the Unites States. Transportation Research Part B, Vol. 44, No. 3, pp.330–357.

[Gal09] Galán, J. M.; L. R. Izquierdo; S. S. Izquierdo; J. I. Santos; R. del Olmo; A. López-Paredes; B. Edmonds (2009). Errors and Artefacts in Agent-Based Modelling. Journal of Artificial Societies and Social Simulation, Vol. 12, No. 1.

[Gil95] Gilbert, N.; R. Conte (1995). Artificial Societies: The Computer Simulation of Social Life. Gilbert, N.; R. Conte (Eds.), s.l., UCL Press.

[Gil99] Gilbert, N.; K. G. Troitzsch (1999). Simulation for the social scientist. s.l., Buckingham: Open University Press.

[Ham19] Hamilton, W. H. (1919). The Institutional Approach to Economic Theory. American Economic Review, 9(1), Supplement, pp. 309-318.

[Har04] Hare, M.; P. Deadman (2004). Further towards a taxonomy of agent-based simulation models in environmental management. Mathematics and Computers in Simulation, Vol. 64, No 1, pp. 25-40. Elsevier Science Publishers B. V.

[Her00] Hernández, C.; A. López-Paredes (2000). Engineering market design and computational organization. Growing the market from the bottom-up. Proceedings of the Workshop on Complex Behaviour in Economics, CEFI, Aix-en-Provence, France.

[Hof10] Hoffman. K.; D. Menon (2010). A practical combinatorial clock exchange for spectrum licenses. Decision Analisys, 7(1) 58–77.

[Kle96] Kleit, A.; B. Kobayashi (1996). Market failure or market efficiency? Evidence on airport slot Usage. Research in Transportation Economics, Vol. 4, No. 1, pp. 1-32.

[Har07] Harris, F. (2007). Large-scale entry deterrence of a low-cost competitor: an early success of airline revenue management. International Journal of Revenue Management, Vol. 1, No. 1, pp.5-27.

[IAT12] IATA (2012). Worldwide Slot Guidelines, 2nd Edition. Montreal, Canada.

[Joh99] Johnson, P. E. (1999). Simulation Modeling in Political Science. American Behavioral Scientist, Vol. 42, No 10, pp. 1509-1530.

[Kle99] Klemperer, P. (Ed.). (1999). The economic theory of auctions. Edward Elgar.

[Lan03] Lansing, J. S. (2003). Complex Adaptive Systems. In Cowan, G. A.; G.C. Rota (Eds.), Annual review of anthropology, Vol. 32, No 1, pp. 183-204. JSTOR.

[Lop01] López-Paredes, A. (2001). Análisis e Ingeniería de las Instituciones Económicas. Una metodología Basada en Agentes. Servicio de Publicaciones de la Universidad del País Vasco. Bilbao. ISBN: 84-8373-347-1.

[Lop04] López-Paredes, A. (2004). Ingeniería de Sistemas Sociales. Diseño, Modelado y Simulación de Sociedades Artificiales de Agentes. Valladolid, Servicio de Publicaciones de la Universidad de Valladolid.

[Mad06] Madas, M.; K. Zografos (2006). Airport slot allocation: from instruments to strategies. Journal of Air Transport Management, Vol. 12, No. 2, pp. 53-62.

[Mal03] Maldoom, D. (2003). Auctioning capacity at airports. Utilities Policy, Vol. 11, No. 1, pp.47–51.

[Mos99] Moss, S. (1999). Relevance, Realism and Rigour: A Third Way for Social and Economic Research. Report No. 99-56, Centre for Policy Modelling, Manchester Metropolitan University. Manchester, UK.

[Mot06] Mott MacDonald (2006). Study on the Impact of the Introduction of Secondary Trading at Community Airports. Technical Report prepared for the European Commission (DG TREN), London, UK.

[NER04] NERA (2004). Study to Assess the Effects of Different Slot Allocation Schemes. Technical Report prepared for the European Commission (DG TREN), London, UK.

[Nic01] Nicolaisen, J.; V. Petrov; L. Tesfatsion (2001). Market power and efficiency in a computational electricity market with discriminatory double-auction pricing. IEEE Transactions on Evolutionary Computation, 5(5):504-523.

[Pel12a] Pellegrini, P.; L. Castelli; R. Pesenti (2012). Secondary trading of airport slots as a combinatorial exchange. Transportation Research Part E 48, pp. 1009-1022.

[Pel12b] Pellegrini, P.; L. Castelli; R. Pesenti (2012). Metaheuristic algorithms for the simultaneous slot allocation problem. IET Intelligent Transport Systems, Vol. 6, Iss. 4, pp. 453–462.

[Ras82] Rassenti, S.; V. Smith; R. Bulfin (1982). A Combinatorial Auction Mechanism for Airport Time Slot Allocation. Bell Journal of Economics, Vol. 13, Issue 2, pp. 402-417.

[Res97] Resnick, M. (1997). Turtles, termites and traffic jams. s.l., MIT Press.

[Rot98] Rothkopf M. H.; A. Pekec; R. M. Harstad (1998). Computationally Manageable Combinatorial Auctions. Management Science, 44, pp. 1131–1147.

[Rot05] Roth, A. E.; T. Sönmezc; M. U. Ünverd (2005). Pairwise kidney exchange. Journal of Economic Theory, 125, pp. 151-188.

[Rot07] Rothkopf, M. H. (2007). Decision analysis: The right tool for auctions. Decision Analysis 4(3), pp. 167–172.

[Sch78] Schelling, T.C. (1978). Micromotives and Macrobehaviors. Harvard University Press. Cambridge, MA.

[Sen03] Sentance, A. (2003). Airport slot auctions: desirable or feasible? Utilities Policy, Vol. 11, No. 1, pp. 53-57.

[Ses07] SESAR Definition Phase (2007). ATM Target Concept, Deliverable D3.

[Ses11] SESAR Development Phase (2011). Airport Detailed Operational Description Step 1, Deliverable D07, Edition 01.00.01.

[Ses12] SESAR Development Phase (2012). Concept of Operations Step 1, Deliverable 65-011, Edition 01.00.00.

[Sta98] Starkie, D. (1998). Allocating airport slots: a role for the market? Journal of Air Transport Management, Vol. 4, No. 2, pp.111-116.

[Ste11a] Steer Davies Gleave (2011). Impact assessment of revisions to Regulation 95/93 - Final report prepared for the European Commission (DG MOVE). London, UK.

[Ste11b] Steer Davies Gleave (2011). Impact assessment of revisions to Regulation 95/93 - Results of stakeholder consultation prepared for the European Commission (DG MOVE). London, UK.

[Sul00] Suleiman, R.; K. G. Troitzsch; N. Gilbert (2000). Tools and techniques for social science simulation. Physica-Verlag HD.

[Tes02] Tesfatsion, L. (2002). Agent-based computational economics: growing economies from the bottom up. Artificial Life, Vol. 8, No 1, pp. 55-82. MIT Press.

[Ton09] Tonmukayakul, A.; M. H. Weiss (2009). A study of secondary spectrum use using agent-based computational economics. Netnomics, Vol. 9 Iss. 2, pp. 125-151.

[Ver10] Verhoef, E. (2010). Congestion pricing, slot sales and slot trading in aviation. Transportation Research Part B, Vol. 44, No. 3, pp.320–329.

[Wol03] Wolfe, L. D. (2003). Dynamics in Human and Primate Societies: Agent-Based Modeling of Social and Spatial Processes. American Anthropologist, Vol. 105, No. 4, December.

[You98] Young, H. P. (1998). Individual Strategy and Social Structure. s.l., Princeton University Press.

[Zog11] Zografos, K.G.; Y. Salouras; M.A. Madas (2011). Dealing with the efficient allocation of scarce resources at congested airports. Transportation Research Part C Vol. 21, pp. 244–256.

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