Final Project Report WP-E

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Abstract

The final report of the ELSA project extension provides a publishable summary of the results. In addition it lists all deliverables, dissemination activities, eligible costs, deviations, bills and lessons learned. All these information are reported in relation to the activities carried out during the project extension. For an overview of the activities carried out in the first phase of the project it is possible to refer to Deliverable D0.10.

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Intellectual Property Rights (foreground)

This deliverable consists of SJU foreground.

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Publishable Summary

The general objective of the ELSA Phase I was to analyse, describe and model the dynamics of the ATM system, especially those concerning the propagation of disturbances (performance and safety related). The analysis was carried out in the current scenario (based on real data). Methods and techniques were selected to be suitable also for the analysis of disturbances in a SESAR scenario. The project had three strands of activity:

- an extensive statistical analysis of data of the ATM system with Complex Systems theory techniques in order to characterize statistical regularities. Example include variation in predictability during the flight execution phase, correlation between traffic and safety metrics, seasonal fluctuations, etc.;
- the development of an Agent Based Model of increasing complexity and degree of realism, to simulate the current scenario and possibly the SESAR scenario;
- the design of a prototype of a decision support tool, based on and informed by the results of the two other strands. The prototype mostly focused on visualising and interacting with some of the phenomena analysed by ELSA, e.g. disturbances to predictability.

In particular, the objective of the Agent Based Model (ABM) activities was to understand which are the main mechanisms underlying the ATM system behavior. The expected outcome was a tool capable of:

1. replicating some of the behaviors observed in the real world system and identified in the data analysis part of the project. For example, the same statistical regularities observed in real data (e.g. most critical navigation points, spatial distribution of controller's actions) should be observed in the model outcomes.
2. supporting the analysis of the ATM working mechanisms and new concepts from SESAR

While ABM modeling process was completed to an adequate extent, the model outcomes could not be fully analysed during the project duration and the model did not reach a sufficient maturity in the current scenario to be extended to the SESAR one. However, preliminary results on the current scenario had shown a good potential for this tool to be successfully extended and to possibly be used as a research tool by the ATM community.

The ELSA project extension moved from the above considerations with the following objectives:

- improving the ELSA ABM in order to make it capable of effectively simulating different ATM operational concepts in current and SESAR scenarios on a larger spatial scale;
- developing a Portable version of the ABM intended as a "Generic ATM simulator" to give the research community a tool to experiment innovative concepts in the ATM environment.

These objectives have been achieved by extending the model to multi-sector level, covering an area as big as an entire FIR. The strategic and tactical phases were also fully integrated to properly simulate a scenario consistent with some of the features foreseen by the SESAR Step 1 Time Based Operations [1].

Moreover, the project has delivered a modular, cross-platform simulator of air traffic management. This simulator was built upon the ELSA ABM and is designed to be used as a complex exploratory tool to study new concepts from SESAR, new organization of the airspace and/or new rules of air traffic management.

The whole work has been supported by continuous validation activities. This helped in defining the right inputs to the modeling process and supported the research activities with interviews with experts and stakeholders in order to improve the effectiveness of the outcomes, in terms of the ability to replicate the SESAR scenario and the usefulness of the produced Portable ABM.

SESAR Agent-Based Model

One of the main objective of the ELSA project extension was to extend the ABM and to use it to address research questions in the current and in the SESAR scenario. The aim was to investigate the issues that affect the predictability of the last filed flight-plan within the ATM system, and what are the changes brought by SESAR in terms of airspace management and controllers' workload. The specific scientific questions the project investigated are:

- What are the issues that affect the predictability of the last filed flight-plan within the ATM
- system? How is the predictability affected by these issues?
- Can sectors capacity be improved by a more efficient management of conflicts?
- What are the impacts of some of the changes foreseen by SESAR on the airspace management and on the controllers' workload?
- Are these changes able to accommodate efficiently the foreseen traffic increase?

The model fully integrated the tactical and strategic layers. The tactical layer of the Agent Based Model aims at describing the interactions between flights and controllers while the strategic layer simulates the submission of flight plans by the air companies to the Network Manager, who computes the sector loads and rejects flight plans if the sector capacity has been exceeded.
As in the first phase of the project, the ABM development was driven by a criterion of simplicity, in order to model only the parameters that are strictly necessary to replicate selected real features. These have been selected in order to effectively mimic the main characteristics of the reference SESAR scenario. In particular the ABM development was targeted at modelling some of the features that are foreseen in SESAR Step1 as described in the Concept of Operations [1]. In particular the consortium modelled:

- The implementation of business trajectories by making requested trajectories from airlines progressively straighter and straighter across sectors and FIRs;
- The increase of the traffic load according to the foreseen forecasts [1][4] by testing the model outcomes when varying the capacity of the airspace up to the maximum foreseen traffic load;
- The improved coordination, information sharing and trajectory prediction available through the implementation of SWIM by simulating conflict-free planned trajectories;
- The new ATM roles with extended look ahead and in particular the role of the multi-sector planner by modelling an extended controller look-ahead time up to 40 minutes.

The current scenario, in which all model parameters are defined from real data analysis, has been used as the baseline. For SESAR different scenarios have been considered, each of them including some of the above features. The aim was to determine the effect of each single feature (straight trajectories, conflict-free planned trajectories, increased look ahead) on the model outcomes.

The results of the analyses carried out in the current and SESAR scenarios address, implicitly or explicitly, most of the four main SESAR KPA: Environment, Cost-Effectiveness, Capacity and Safety. In particular the following main results and related operational benefits can be identified:

1) ***Safety improvement from the reduction of total number of conflicts and reduction of controller workload.*** According to the results, controller's activity in the SESAR scenario will change, moving from a situation where he has to give attention to a high number of conflicts concentrated in specific points to a situation where he will have to manage less conflicts spread in a much larger portion of the airspace. This will imply a quantitative and qualitative change of controller's workload. Quantitative in a sense that total workload will be reduced while qualitative in the sense that nature of controllers tasks will be changed (shifting from mainly conflict resolution to mainly traffic monitoring tasks). In fact as reported in Figure 1 and Figure 2 when increasing the efficiency of the airspace structure (i.e making trajectories straighter keeping the same controller's look-ahead) the average number of conflicts (and thus of controller's actions) diminishes and they are spread on a wider area. Moreover, this behavior is not dependent on the number of flights thus implying that SESAR scenario will provide the same benefits also in a situation with increased

traffic load. This analysis has been conducted on different ACC evidencing the same general behavior in all of them.

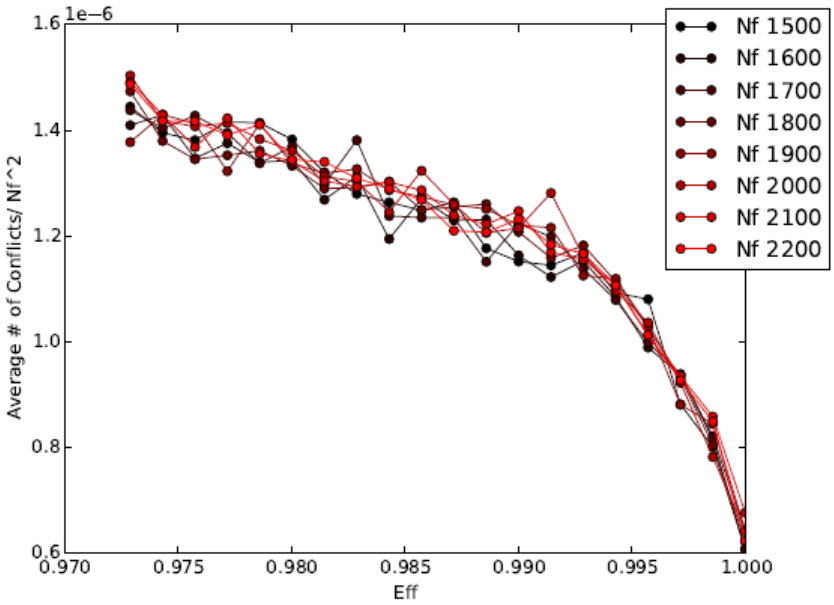

Figure 1: Average number of conflicts detected in the flight trajectories of the LIRR ACC, for different values of efficiency (horizontal axis) and for different values of the aircraft present in the ACC (Nf).

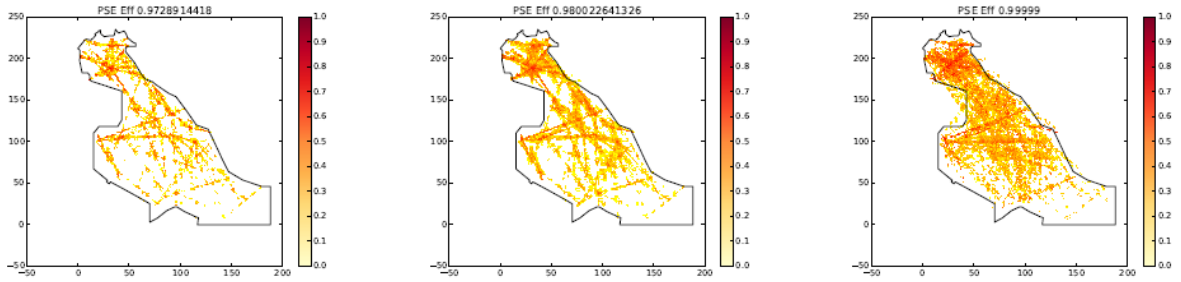

Figure 2: Density map of the conflicts (PSE) detected when considering three different levels of efficiency in the LIRR ACC. When increasing the efficiency (moving from left to right) conflicts are spread on a wider area.

2) ***Capacity definition, predictability and system costs reduction.*** From most of the analyses carried out (see point 1) it emerged that the definition of capacity in the SESAR scenario will have to take into account the shifting of the controller workload from mainly conflict resolution to mainly monitoring tasks. Moreover, results showed that rectifying trajectories is beneficial for the general efficiency of the system. By looking at Figure 3 it can be seen that in SESAR scenario sector throughput (traffic load) is mostly lower than sector capacity due to the fact that traffic is spread across the airspace leading to more balanced traffic load among sectors. This result has been obtained in a condition where planned trajectories are perturbed not only by conflicts with other flights but also with shocks (forbidden areas representing weather events or military areas).

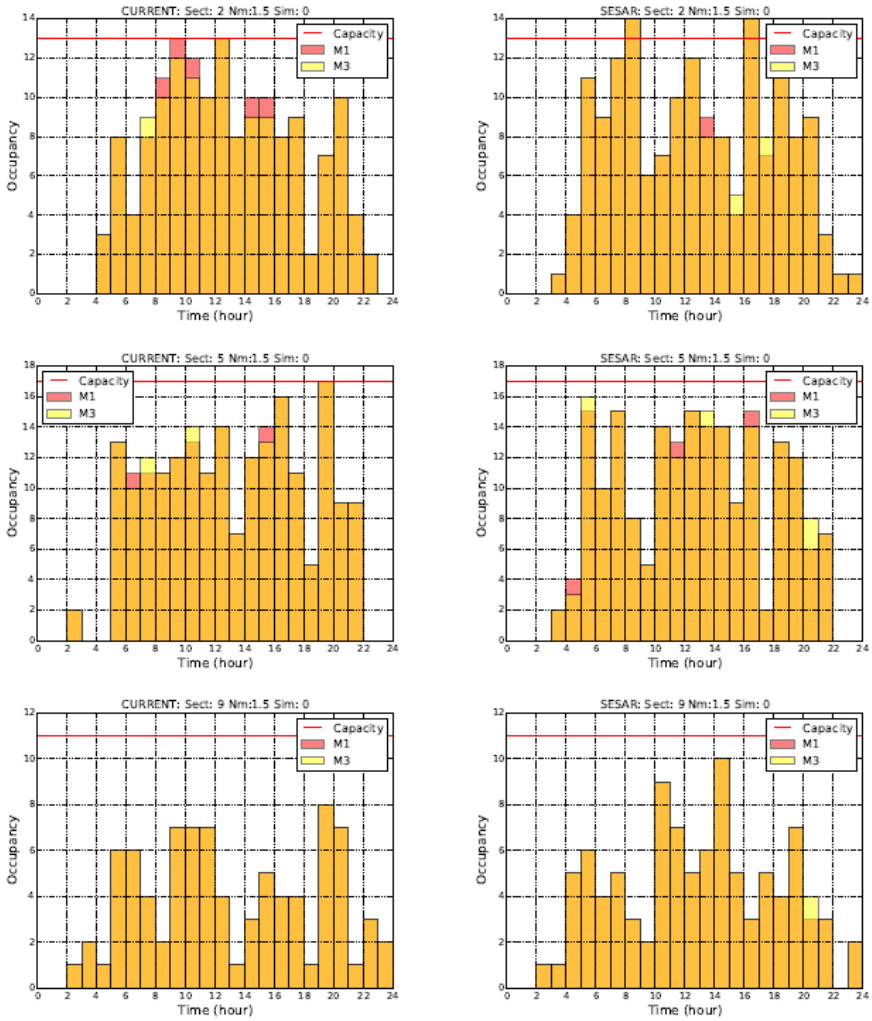

Figure 3: Sectors occupancy over the 24 hours for the current (left) and the SESAR scenario (right) for three sectors in the LIRR FIR. When red is visible this indicates that planned occupancy is larger than the actual one. The opposite when yellow is visible. Orange indicates that occupancy in the planned trajectories equals capacity in the simulated trajectories.

3) Improved airspace management. Results related to the scenario where controllers have an increased look-ahead showed that in SESAR scenario (i.e. with straight trajectories) this increase will have the consequence of reducing the number of actions shifting workload from Executive air traffic controller (EC) to Planning air traffic controller (PC), i.e. EC will have lower workload due to more monitoring tasks and less conflict resolution and separation assurance tasks. Given that controller have a tool to monitor the traffic (e.g. Medium Term Conflict Detection), all the actions could be taken at the entrance of the airspace. This could lead to a standard procedure where pilots systematically receive instructions at the entrance of a controlled area and then fly free. In fact, as reported in Figure 4, with a higher look-ahead controller's actions will reduce in number (the highest number of actions reduces from around 18 to 8) and will be located in some specific areas thus potentially reducing the overall workload in presence of a Monitoring Tool to support subsequent tasks.

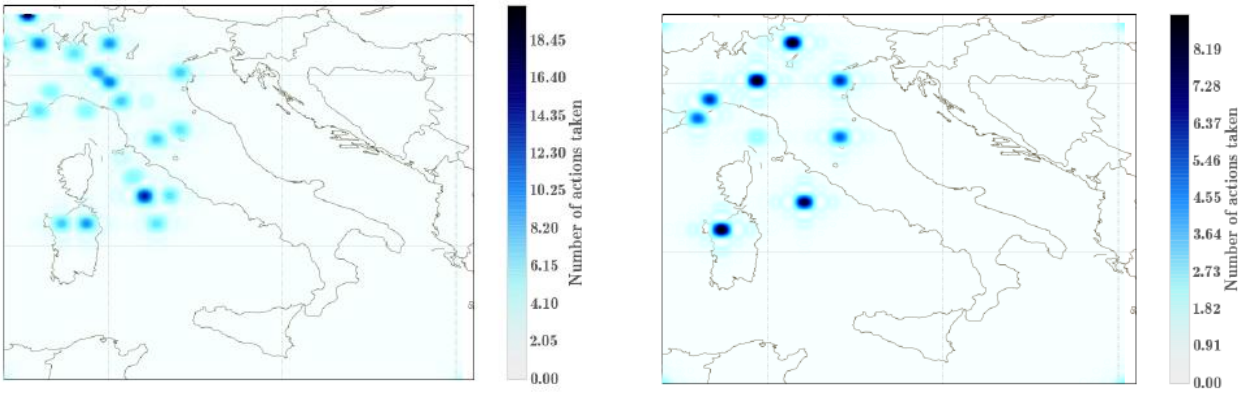

Figure 4: Spatial location of the actions taken by the controller with low (15 min, left panel) and high (40 min, right panel) look-ahead

Portable Agent-Based Model

The other output of the ELSA project extension is the Portable version of the Agent-Based Model named “ELSA Air Traffic simulator”. The objective of this activity was to make the ABM a modular, cross-platform simulator of air traffic management. The structure of the ABM and its functionalities were kept and effort was invested in developing a more user-friendly interface and all the required documentation and support material. The ELSA Air Traffic Simulator has therefore been designed to be used as a tool to study new concepts from SESAR, new organization of the airspace and/or new rules of air traffic management. The primary users are from academy, because the model does not provide a sufficiently realistic description of the traffic as it is for more operational users. As such, it is meant to be used as a scenario generator for synthetic data generation.

The code has been designed to be modular, i.e. that the user can use the different parts in a fairly independent way. The ELSA Air Traffic Simulator is based on interacting agents (mainly flights and controllers) and is composed by the following modules:

- A **network generator**, including navpoints and sectors.
- A full **strategic layer** and a simplified traffic generator, used to test different traffic situations.
- A **rectification module**, used to straighten up trajectories when simulating free-routing,
- A **tactical layer**, with a conflict resolution engine, simulating a tunable, imperfect super-controller.
- A **post-processing module**, including standard metrics computation and a simple graphic interface to see isolated run.

A schematic representation of the code is displayed in
Figure 5.

The code has been written in Python and C. The choice of non-proprietary languages ensures the continuity of the development process and allows to use heavily tested and highly optimized libraries. Python, which is a scripting language, has been chosen for its simplicity, its portability, and the presence of many scientific libraries. It has been preferred to low-level languages for the parts of the model featuring dedicated agents with limited access to memory because of its object-oriented characteristics, fitting the idea of agents. Parts of the code which required less agentification and more optimization have been written in C, a very wide-spread low-level language for which many libraries are also available. Python has also been used to provide simple interfaces to the C code, to help the user using these parts more easily.

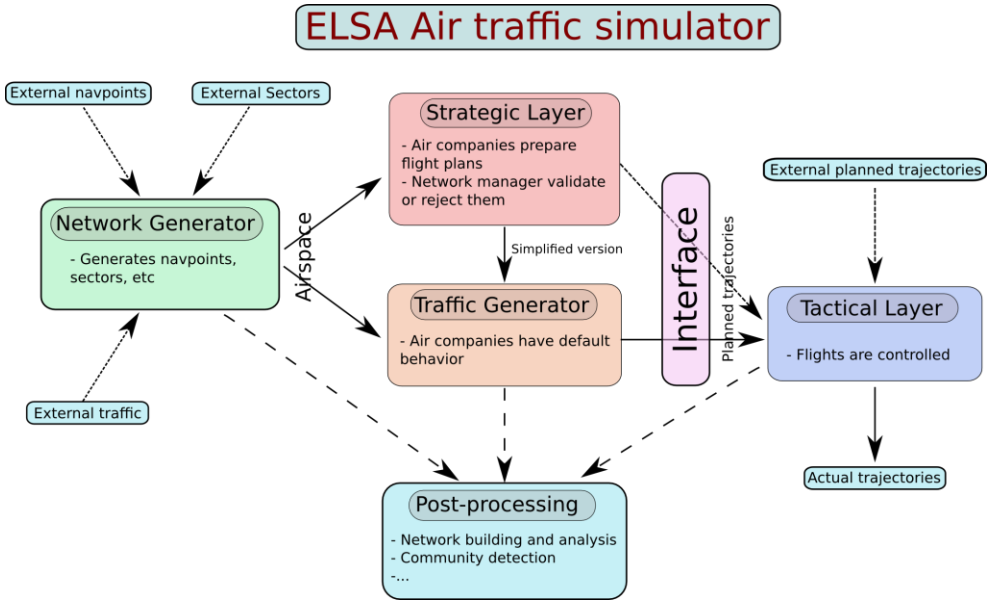

Figure 5: Organization of the ELSA Air Traffic Simulator

The code has been released under the General Public License version 3, which means that it is open-source and freely downloadable. It is hosted on Github at the address https://github.com/ELSA-project/ELSA-ABM. Github provides free hosting as well as handy tools for distributed development, like a wiki, an issue tracker, etc. In other words, it allows anyone to download the code, modify it, submit the changes, discuss about them and so on. It is one of the most popular repositories for open-source software and hosts some of the most famous ones.
The release has been accompanied by basic documentation, an install guide and a set of three tutorials to help the user in understanding the potential use of the simulator. The tutorials included are the following:

1) How to adapt the current **shocks module** (used to model weather events and highly congested areas) and how to plug in a customized one. The user is guided through the steps needed to test its own weather models or airspace occupancy models and their relationship with ATM performances. It describes also how to include the possibility of forecasting these shocks (how they move and when and where they appear and disappear).
2) How to define different behaviours of the controllers in each different sector. This tutorial explains how to modify the current **conflict resolution module** or how to plug in a customized one. The user is guided through the steps needed to fully customize the controlling parameters in each area of the airspace at different granularity levels (sector, FIR, FAB). These parameters include: directs probability, angle of re-routing, velocity change range.
3) How to define a different structure of the airspace. This tutorial explains how to modify the current **airspace generator module** or how to plug in a customized one. The user is guided through the steps needed to generate the airspace structure according to a set of predefined parameters such as: average size of sectors, density of sectors in each FIR. It also describes how to define manually the FIR boundaries along with the sectors inside it and each single navpoint.

Potential users have been involved from the early phases of the project to ensure that their needs, wants, and limitations were given adequate attention at each stage of the design process. The main target users identified included the ATM research community and in particular experienced researchers, PhD students and anyone involved in ATM and more specifically in SESAR related research activities from various Universities and Research Centres all over Europe (NLR, Innaxis, ENAC, TU-Delft, Universities of Rome, Belgrade, Bologna, Hannover). The requirements gathered by the target users have been taken into consideration during the development process.

Conclusions

The results achieved and the foreseen benefits for the SESAR community coming from the work carried out during the ELSA project extension are the following:

- Measuring in quantitative terms the degree of optimisation brought by SESAR concepts in normal conditions, including also aspects like the number and type (e.g. tactical vs. planning) of ATCOs' actions,
- Providing a tool with the capability of testing different future scenarios, for instance by simulating the transition period, when a SESAR concept is being implemented, but not fully deployed,
- Providing a common platform to be used by the SESAR research community, to make it easier to compare different research programs, or to provide synthetic data for data mining algorithms testing.
- Building a community of researchers interested in exploiting the potential of Agent-Based Modelling in ATM research.

Future research based on ELSA project results

Two main results of the whole ELSA project can be exploited for future research. First, methods and tools developed within ELSA to numerically describe the current ATM system at the EU level could be used to measure the benefits brought by the implementation of SESAR concepts, e.g. integration of sectors in FABs, user-preferred trajectories. They can also be used to identify proxies of behavioural patterns in the ATM system at large. Analysis of these can allow to dig into the complexity of the ATM system and identify non-trivial deviations. Performance improvements could then be gained by addressing research questions such as:

- What are the drivers behind these deviations? What are their precursors or early warning signals?
- How can they be replicated/eliminated?

Secondly, the ELSA simulator itself can be potentially used to run different scenarios, applying the ELSA analyses to measure with rigorous quantitative metrics the achieved optimisation, compare different solutions, carry out stress tests to see how various configurations cope with shocks like strikes, bad weather, large volcanic ashes, and so on. Future research can also build on the current version of the simulator by extending its scope to make it capable of investigating new concepts such as the impact of information sharing on the airlines business choices, or the system resilience in presence of major disruptive events.

The above research ideas constituted the basis of a proposal submitted under the H2020 Exploratory Research call by a Consortium composed by members of the ELSA team and other European researchers.

1 Introduction

1.1 Purpose of the document

The purpose of this document is to:

- Summarise the technical results and conclusions of the project extension (Publishable Summary);
- Provide a complete overview of all deliverables;
- Provide a complete overview of all dissemination activities carried out during the project extension (past and in progress).
- Provide a complete overview of the billing status, eligible costs, planned and actual effort (incl. an explanation of the discrepancies).
- Analyse the lessons learnt at project level during the extension phase.

All the above information are reported in relation to the activities carried out during the project extension. For an overview of the activities carried out in the first part of the project it is possible to refer to Deliverable D0.10.

1.2 Intended readership

The document is intent to be used by the ELSA Project Officer, the SESAR JU and EUROCONTROL organizations to have an overview of the ELSA project extension, its results and lessons learnt. The document also contains a summary of the project deliverables, dissemination activities, eligible costs and bills and provides a picture of the project activities in the past 12 months.

1.3 Glossary of terms

Term	Definition
ABM	Agent-Based Model
ACC	Area Control Centre
AIRAC	Aeronautical Information Regulation and Control
ANSP	Air Navigation Service Provider
AOC	Aircraft Operations Centre
ATM	Air Traffic Management
DBL	Deep Blue
ECAC	European Civil Aviation Conference
EEC	EUROCONTROL Experimental Centre

Term	Definition
ELSA	Empirically grounded agent based models for the future ATM scenario
FIR	Flight Information Region
NM	Network Management
SESAR	Single European Sky ATM Research Programme
SJU	SESAR Joint Undertaking (Agency of the European Commission)
TMA	Terminal Manoeuvring Area
UniPa	University of Palermo
WP	Work Package

2 Technical Project Deliverables

Number	Title	Short Description	Approval status
D4.4	Validation Plan	This deliverable presents the validation plan for the ELSA extension, detailing the objectives, the planned exercises, and the interactions between the validation Work Package and the technical Work Packages.	Approved
D2.4	SESAR Agent-Based Model	This deliverable presents the Agent Based Model developed within the extension of the ELSA project. The deliverable describes the different modules of the model and the way numerical simulations have been implemented. These have been performed with the aim of showing how the different modules of the model can work as a SESAR scenario simulator to assess different operational concepts.	Approved
D2.5	Portable Agent-Based Model	This document presents the ELSA Portable Agent-Based Model. Its objective is to provide i) a description of the development process, including the validation activities, ii) a description of the software components and iii) a basic guide for users including three tutorial to perform specific analyses and to customize the model.	Submitted
D5.6	SID Abstract	This document will contain the paper and slides to be presented at SESAR Innovation Days 2015. The paper will present the SESAR Agent Based Model developed as part of the ELSA project extension and the main results of the simulations.	To be submitted by Semptember 21st

Table 1 - List of Project Deliverables

3 Dissemination Activities

During the ELSA project extension, specific effort has been devoted to disseminate the results of the Phase I project activities and to prepare the ground for the dissemination of the extension results. The work carried out during the first and the extension phases has regularly being submitted to various conferences and events associated to various communities. An article presenting the work done in the ELSA project extension will be submitted to the SESAR innovation days 2015. Also, the project updated its wiki page on the Complex World website to disseminate towards the general public and the Complex World Network the work done about the development of an Agent Base Model for the ATM research community.

3.1 Dissemination towards General public and Complex World Research Network

The ELSA Project wiki page, available at the following address: http://complexworld.eu/wiki/ELSA, was updated and a dedicated page with a description of the ELSA Agent-Based Model has been created: http://complexworld.eu/wiki/ELSA_Agent_Based_Model

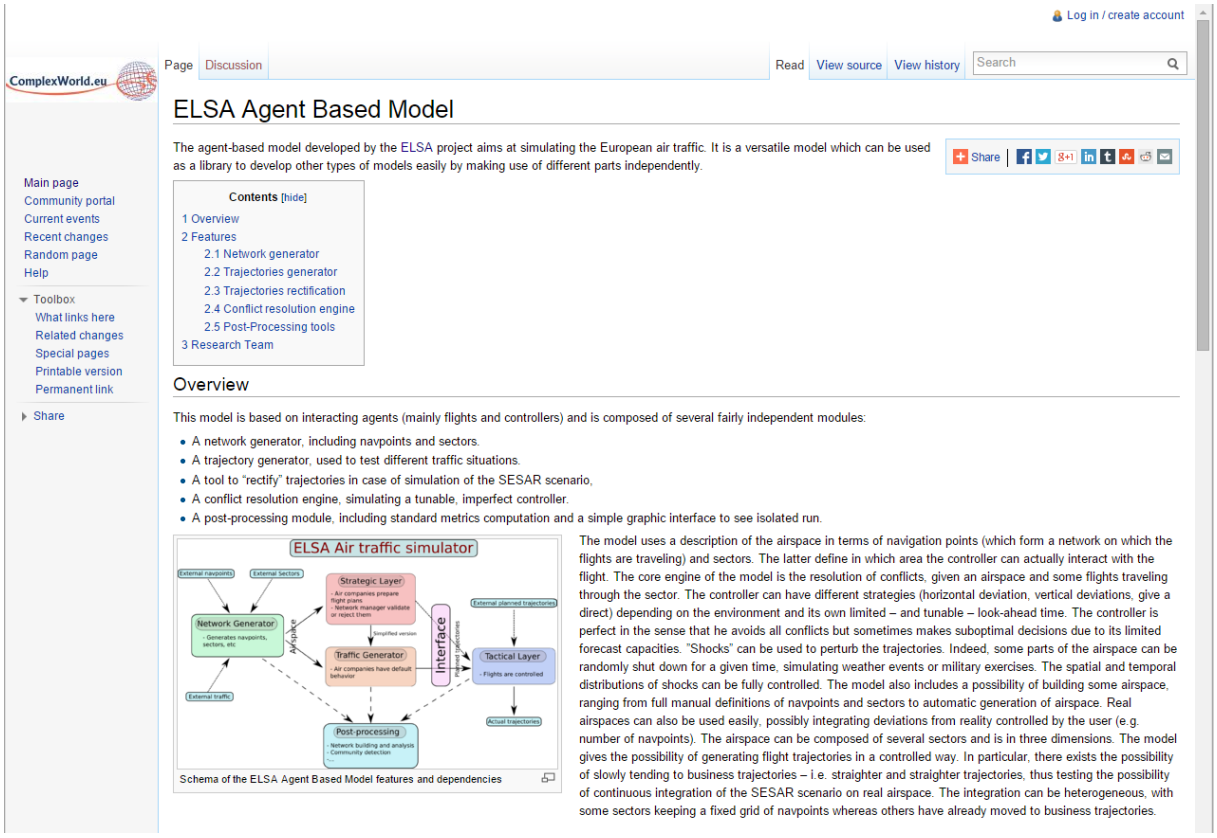

Figure 6: ELSA Agent-Based Model wiki page – Complex World

3.2 Dissemination towards the ATM public

No specific dissemination of the ELSA extension results has been carried out so far towards the ATM public. However, results of project phase I have been presented in various occasions to the following audiences:

- ANSPs Safety Managers and Safety Experts,
- ENAV Safety Unit,
- Eurocontrol SPIN Sub-Group

3.3 Presentations at SESAR innovation days (SESAR community)

SESAR innovation days have always been an opportunity to present to the SESAR community the on-going work and the achievements of the ELSA project. By SID 2014, the ELSA extension results were not mature enough. Therefore the project is planning to present its final outcomes at SID 2015.

3.3.1 SESAR Innovation Days, Bologna, Italy, December 1-3, 2015

For SID 2015 the project members are planning to submit a paper describing the theoretical framework and the main results of the SESAR Agent Based Model. This paper will include a description of the main modelling assumptions, the results achieved and the future perspectives. Moreover, the paper will present the portable version of the ELSA ABM, with a specific focus on the potential applications and related benefits for the ATM research community.

3.4 Presentation at other ATM conferences

3.4.1 Complexity Challenges and Opportunities in SESAR2020, Brussels, Belgium, April 7, 2015

The experience of the ELSA project have been presented with respect to the “Challenges and opportunities for ATM metric development”. In particular it has been described the work carried out within the project about the identification and definition of “non-conventional” metrics for the description of the ATM system. It has been reported which are these metrics, how they can be used to improve the understanding of the ATM processes and more in general which are the challenges and opportunities related to their use.

3.4.2 USA-Europe ATM R&D Seminar, Lisbon, Portugal, June 23-26, 2015

For the USA-Europe ATM R&D Seminar, the ELSA project team submitted a paper entitled: “Adaptative air traffic network: statistical regularities in air traffic management”. In this paper, starting from traffic data on flights trajectories – planned and actual ones – in Europe, we build a navigation point network. We study this network which exhibits different features for different European countries. In particular, some countries uses a high number of navpoints, facilitating the planning of the flight plan by air companies at the cost of higher concentrations of traffic in few nodes. Making use of the deviations from the planned trajectories, we find that once again different countries have different control procedures with respect to traffic management. Interestingly, we find that some countries tend to make more deviations when the traffic conditions are low. Moreover, they tend to concentrate the deviations in a few number of nodes, especially during daytime. Finally, the position of these key navigation points are sometimes stable over the days, which shows a consistent use of some navpoint for the same kind of rerouting operations.

The actual presentation at the conference constituted also an opportunity to present the development of the ELSA ABM and its potential use as a generic Air Traffic Simulator for the ATM research community.

3.5 Presentations/publications at other conferences/journals

3.5.1 NECTAR Cluster 1 Workshop, Cranfield, UK, May 6-7 2015

For the NECTAR workshop, the ELSA project team submitted an abstract entitled: “Adaptative air traffic network: statistical regularities in air traffic management”. Despite the same title as the paper presented at the ATM R&D Seminar, the presentation given at this workshop was more devoted to the Complex Systems research community rather than to the ATM one. For this reason the focus was more on the theoretical background and the methodology to apply Complex Network Theory to ATM.

Also in this occasion, the ELSA ABM was briefly presented and advertised as a tool for the ATM research community and for the Complex Network community at large.

3.5.2 ICCSS, Helsinki, June 8-11 2015

For the International Conference on Computational Social Science the ELSA project team made a presentation entitled: “An agent based model of air traffic management”. The presentation was entirely dedicated to showing the Air Traffic Simulator developed during the project extension. Details were given on how the model works, how it is calibrated and what are the results that can be obtained with it.

3.6 Publications on other journals

The ELSA team members submitted a paper entitled “Competitive allocation of resources on a network: an agent-based model of air companies competing for the best routes” to the Journal of Statistical Mechanics. The paper was published in May 2015.

The paper presents the research carried out with the Strategic layer of the ELSA Agent-Based Model. In particular a stylized model of the allocation of resources on a network is presented. By considering as a concrete example the network of sectors of the airspace, where each node is a sector characterized by a maximal number of simultaneously present aircraft, we consider the problem of air companies competing for the allocation of the airspace. Each company is characterized by a cost function, weighting differently punctuality and length of the flight. We consider the model in the presence of pure and mixed populations of types of airline companies and we study how the equilibria depends on the characteristics of the network.

3.7 Exploitation plans

The results and lessons learnt from the ELSA project will benefit the Deep Blue Company, the University of Palermo research unit and the research community (especially in the fields of Complex Systems and Agent Based Modeling).

3.7.1 Expected benefits for Deep Blue

In general, the ELSA Air Traffic Simulator will be exploited whenever possible into other R&D activities, including other SESAR 2020 Exploratory research projects in order to advance its maturity and extend its potential use beyond the research community to make it exploitable also at the market level.

The experience acquired in the user-centred design process used to develop the ELSA Air Traffic Simulator will be exploited in other existing and future activities in both research and consultancy projects. This exploitation will require additional work to customise the process for the specific user needs.

3.7.2 Expected benefits for the University of Palermo

The research unit at the University of Palermo has gained significant expertise in the area of development of Agent Based Models and their calibration on real data. These competences will be useful in many other research activities of the Palermo research group, not only in the research on air traffic activities but also on other topics, such as complex systems of social, financial and economic nature. Moreover the competences and knowledge acquired with the ELSA project could be used for further empirical analyses, to advance the level of maturity of the ones already discovered and to identify new statistical regularities for example concerning the way this socio-technical complex system reacts to major stress events such as in the case of the volcano eruption in Iceland in April 2010. Finally, the results of the ELSA project have been the basis for a new grant proposal recently submitted to the H2020.

3.7.3 Expected benefits for the research community

The main benefits delivered by the ELSA project extension to the research community are the following:

- The development of a modular, cross-platform simulator of air traffic management to be used as a tool to:
    - Study new concepts from SESAR,
    - Study new organization of the airspace and/or new rules of air traffic management
    - Generate synthetic data for data-mining algorithm testing
- The development of a community of researchers interested in exploiting the potential of Agent-Based Modelling in ATM research by sharing experiences and tools for data analysis and simulations.

4 Total Eligible Costs

This section is based on the Project Costs Breakdown Forms of the eligible costs incurred by project participants.

Date	Deliverables on Bill	Contribution for Effort	Contribution for Other Costs (specify)	Status
23/06/2015	D4.4, D2.4, D0.11	€ 45.153,96 DBL Fare 75% UNIPA Fare 100%	Travel: € 4481,10 Other costs: € 38,66	Billed, To be paid
foreseen 20/09/2015	D2.5, D5.6, D0.12, D0.13	€ 38.355,32 DBL Fare 75% UNIPA Fare 100%	Travel: € 2.300	To be billed
GRAND TOTAL		€ 83.509,28	€ 6.819,66	

Table 2 Overview of Billing

Company	Planned man-days	Actual man-days	Total Cost	Total Contribution	Reason for Deviation
Deep Blue	210	217,7 (90,2 actual – last invoice missing)	€ 35.788,23 tot actual costs (invoice 1) Last invoice missing	€ 26.841,17 (contribution for effort) Last invoice missing	No relevant deviation
University of Palermo	180	185,8 (135,8 actual – last invoice missing)	€ 22.832,56 tot actual costs (invoice 1) Last invoice missing	€ 22.832,56 (contribution for effort) Last invoice missing	No relevant deviation
GRAND TOTAL	390	403,5 (226 actual – last invoice missing)	€ 58.620,79 tot actual costs (invoice 1) Last invoice missing	€ 49.673,73 (contribution for total effort) Last invoice missing	No relevant deviation

Table 3 Overview of Effort and Costs per project participant

5 Project Lessons Learnt

The lessons learnt reported in the table below refers only to the extension phase of the ELSA project. For a complete list see D0.10 Final Project Report.

What worked well?
Involvement of users and building a research community on ABM. Most of the potential users contacted showed good interest in the ELSA Agent Based Model. ELSA has been seen also as a good occasion to build a research community around the use of Agent-Based Modelling in ATM. This community could be the place to share positive experiences and to learn from them.
Support received from SESAR expert appointed to the project. He helped in defining the right input for the modelling phase and in validating the outcomes identifying the operational benefits of the proposed results. He provided valuable support in steering the research work towards concrete outcomes, both with general comments and with detailed suggestions.
What should be improved?
Interaction with users. Although they were interested in the development of the ELSA ABM we found difficult to practically involve them in the evaluation of the software. This is probably due to the fact that the code was released later than expected giving not enough time to organize a face-to-face workshop but forcing to rely on email and phone contact.
Difficult to understand from the beginning the coding implications of including specific features in the model. When developing software, especially when you are modelling something which is not fully deterministic, it is difficult to foresee how much effort is required to translate into a working code a specific feature. The development of the ELSA ABM faced this problem in some occasion thus preventing from implementing some features (e.g. multi-agent model) and delaying somehow the final release of the code.

Table 4 - Project Lessons Learnt

6 Support from external experts

The ELSA project team was supported by SJU expert [redacted] from University of Belgrade.

A one day meeting with him was organized on the 22nd January 2015.

Several further interactions took place via teleconference and email, to validate the ABM results and to guide the development of the Portable ABM.

7 References

[1] SESAR, “SESAR Concept of Operations Step 1,” 2012.

[2] G. Gurtner, F. Lillo, R. Mantegna, S. Micciché, C. Bongiorno, S. Pozzi, Adaptative air traffic network: statistical regularities in air traffic management, USA-Europe ATM R&D Seminar, Lisbon, Portugal, June 23-26, 2015

[3] G. Gurtner, L. Valori, F. Lillo, Competitive allocation of resources on a network: an agent-based model of air companies competing for the best routes Journal of Statistical Mechanics: Theory and Experiment 2015 (5), P05028

[4] EUROCONTROL, “Challenges of Growth – Task 4: European Air Traffic in 2035”, 2013