Final Project Report WP-E

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Abstract

The final report of the ELSA project provides a publishable summary of the results. In addition it lists all deliverables, dissemination activities, eligible costs, deviations, bills and lessons learned.

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Publishable Summary

The motivation of the ELSA project is the foreseen shift from the current airspace structure to the SESAR concept, with user-preferred trajectories and Functional Airspace Blocks. These changes will be hardly understood by relying on the analysis of single elements, i.e. by applying the current state-of-the-art validation approaches. The characteristics of the future ATM system will instead emerge out of the interactions among all the different changes as delivered by SESAR, producing effects on different levels, from local to EU-wide.

The science of complex systems offers methods and techniques to capture exactly these phenomena. ELSA explored this research area, addressing the following research questions:

- Which are the methods to analyse and monitor the emerging characteristics of the ATM system?
- Can the application of complex system science to ATM provide means to analyse and monitor the ATM system?

The general objective of the project 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, with Trajectory-based operations.

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, with performance-based operations;
- 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.

Two limitations applied to the ELSA work. Firstly, the dataset that was made available to ELSA had a given time and space coverage (e.g. only en-route portion of the flights). Project objectives were revised accordingly. Second, the Agent Based Model did not reach a sufficient maturity in the current scenario to be extended to the SESAR one.

Statistical regularities

The analysis was refined through a series of iterations, starting very early in the project. The initial proposed list of 27 analyses was narrowed down to 8 analyses, to then result in 5 best analyses. The key driving criterion in this selection was the potential benefit for the ATM community, iteratively validated with different stakeholders: ATM experts, safety experts, ANSPs.

The analysis goals were also progressively refined in terms of feasibility and fit with the available data. The final goals were defined as:

- analyse changes and variation in predictability during execution phase of the flight,

- analyse the sensitivity of predictability to external disturbances, like weather and traffic load,
- analyse the sensitivity of predictability to change of user strategies, i.e. NM and Airlines.

The final list of best analyses includes the following:

1. Seasonal variations of communities:

This analysis was used to detect sets (communities) of nodes (airports, or sectors, or navpoints) clustered together. Communities are generically defined as sets of nodes that are more connected among themselves than with the rest of the network. The variations of communities during a period of time (day, week, month, year) can be analysed. See Figure 1.

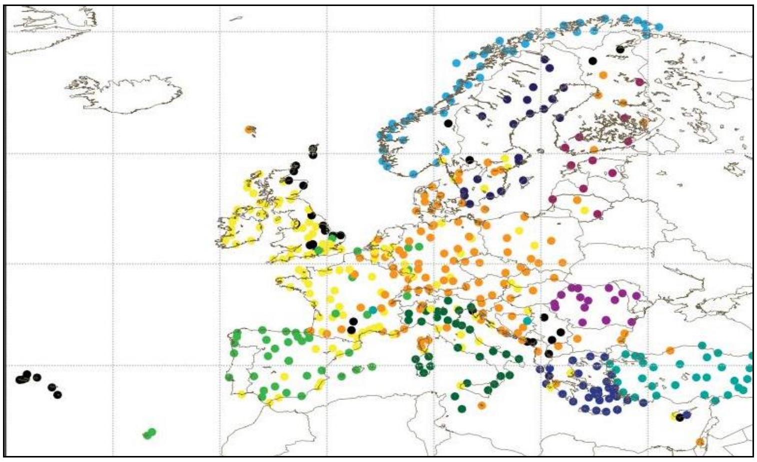


Figure 1. Community analysis of EU airports.

2. Community analysis of the impact of the ash cloud:

This analysis applies the same method of the previous one (community detection), but it focuses on special events, like the volcanic ash cloud in 2010. Compared to the previous analysis a finer time resolution is needed, to detect changes in the community during the day.

3. Analysis of ATCO management strategies: differences among countries and sectors:

Quantitative metrics (i.e. average delay accumulated by all flight passing through a selected area in one hour) are used to describe the ATCOs' controlling strategies and to compare their behaviour across different countries and in time. For instance the negative delay (i.e. time gained) was correlated to the number of flights for different countries or single sectors. See Figure 2.

4. Analysis of the correlations between STCA events and Complex Network metrics in the Rome FIR:

The correlation between the occurrences of safety events (i.e Short Terms Conflict Alerts) and network metrics was calculated, by matching the number of safety events with specific fixes. A high correlation is found between safety events and the fixes' strength and betweenness. Two thresholds are also found, one below which safety events tend to zero, and one above which there is a high probability of a high number of occurrences.

5. Analysis of the most critical navpoints of the Italian airspace:

The Italian airspace was analysed in order to identify the most critical navpoints in terms of two specific network metrics: Strength and Betweenness. The rankings obtained with these metrics were compared with the operational experts' subjective assessments. Almost all the critical navpoints identified by ENAV experts were among the first positions in the ELSA rankings. The end goal of this analysis is to build a quantitative taxonomy of fixes and to match it with the experts' knowledge.

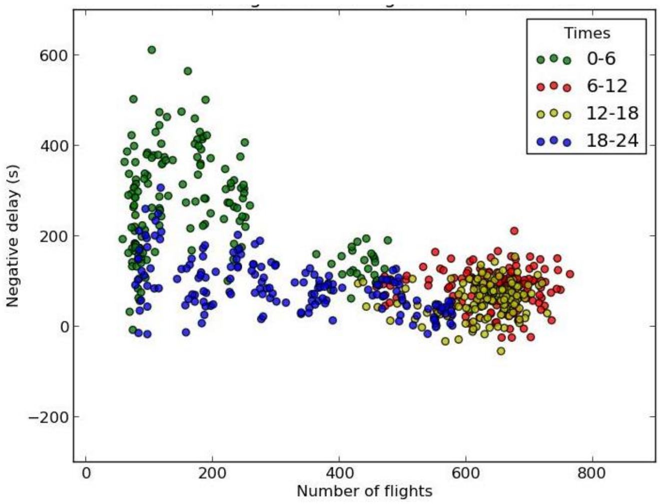


Figure 2. Changes in delays during the day.

Each of the best analysis is described with a standard format, covering the following points: proposed solution, expected benefits, limitations of the proposed solution, enablers and constraints.

Potential future applications of the proposed analyses include the following.

- Community analysis: inform sectorisation with the analysis of traffic flows, validate the applied sectorisation by post-flight analysis.
- ATCOs management strategies: develop indicators to monitor ATCOs' behaviour and detect unexpected deviations, inform definition of business trajectories with post-flight analysis.
- Correlation between network and safety metrics: identify hotspots to be monitored, identify resilient areas to be analysed and re-inforced, correlate safety KPIs with network characteristics and load.
- Critical navpoints: support to airspace design activities. This analysis can be done for post-flight analysis (based on actual trajectories), but also to predict the position of critical points (based on the user preferred trajectories). This feature will be useful in a SESAR scenario, with no fixed airway structure.

In general, these analyses may bring benefits to the ATM community by supporting a data-driven approach to monitoring and managing the airspace. NOP and ANSPs may use them to detect hidden problems, or regularities over different time periods (from one single day to months, or a whole year).

In particular, the analysis of correlation between safety occurrences and network metrics has been recognized by ATM safety expert (ENAV and MUAC Safety teams, EUROCONTROL DNM Safety Unit) as already mature. It can be proposed as a tool for Safety Monitoring (Commission Implementing Regulation (EU) No. 390/2013), that could already be introduced into operations.

Agent-Based Model

The ELSA Agent Based Model was developed to reproduce some of the stylised facts observed in the Air Traffic Management of the European airspace. The model itself had two main parts: (i) The strategic layer, focused on the interaction between the Network Manager and the Airline Operators and (ii) the tactical layer, focused on flight and controllers' interaction at the level of one sector.

The ABM development was driven by a criterion of simplicity, in order to model only the parameters that are strictly necessary to replicate the selected real features. The rationale of this choice was to completely control what was happening in the model, in order to clearly understand how the various factors contribute to the end results. Validation activities were carried out as much as possible to calibrate both layers on ATM real features.

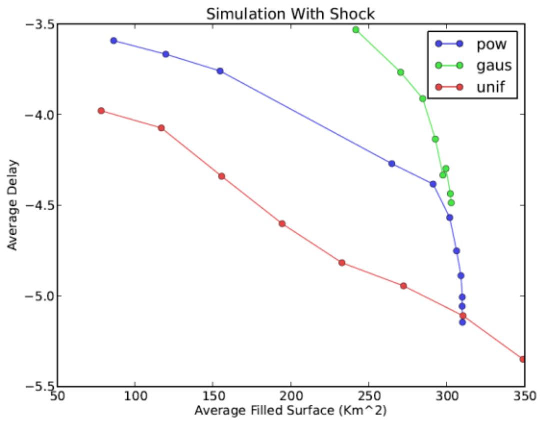
ABM Tactical layer

The tactical layer of the Agent Based Model aims at describing the interactions between flights and controllers in a single Air Traffic Control (ATC) sector. This model was calibrated against real data and used to simulate the current ATM scenario, in order to investigate how the presence of shocked areas affects the system performance. Simulations were run for cases when airspace areas are closed to air traffic, for example for adverse weather conditions, or military manoeuvres. Different possibilities regarding the concentration and size of these areas were considered, e.g. small randomly distributed shocks, or small shocks clustered one next to the other.

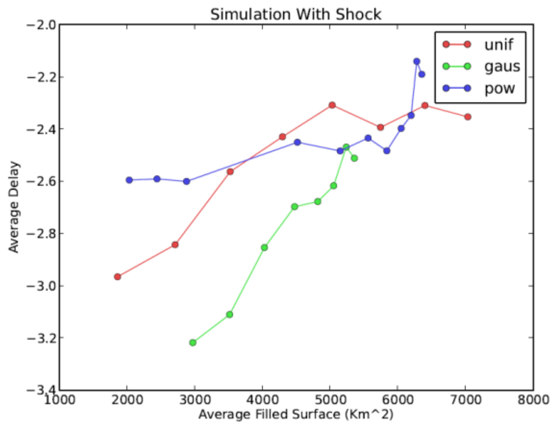
The main result of the ELSA model is that the larger the porosity, the smaller the delay – where porosity is measured as the available volume divided by the total volume of the sector. Another result is that the model generates trajectories that are more optimized than planned ones in terms of the total time needed to cross the sector. This result seems to revert when shocked areas with larger radius are considered (see Figure 3).

This result indicates that the system seems to have room for optimization. For relatively small shocked areas the model optimizes the flight trajectories, resulting in overall negative delays. This effect is also present when there are no shocked areas and the model is therefore simply making trajectories conflict free. Small shocks that are uniformly distributed leave more room for optimization, rather than small concentrated shocks.

Shocks – 5NM radius



Shocks – 25NM radius



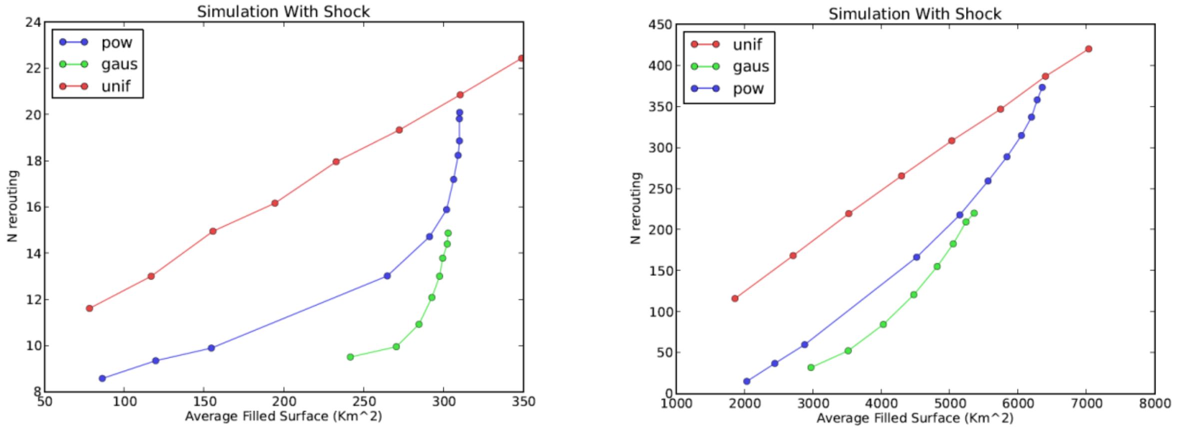


Figure 3: Average delay and number of rerouting when the sector is filled with shocks of different size and different distributions (unif=unfrom, gaus=Gaussian distribution, pow=power law distribution). If the shocks are small the delay decreases when the number of shocks increase, while the opposite happens for larger shocks.

The potential application of the tactical ABM is to provide a sandbox, a generic ATM simulator, where to test innovative concepts and measure the degree of optimisation that could be achieved. As compared to current model-based simulations, the ELSA ABM is designed as to capture the characteristics and regularities of a generic sector, not of a specific geographic area or a specific traffic sample. It can be used to compare different concepts, without polluting the results with geo-specific factors. For this application to become more mature, ELSA would need to enlarge the scope of the current simulator, to reproduce different sector types, and to combine these sectors into a multi-sector simulator. The target simulator will have the capability of moving from the current scenario to a SESAR scenario, by acting on two main elements: (i) Progressive integration of sectors into larger control areas, to reduce the current fragmentation, (ii) Implementation of user-preferred trajectories, by optimising the travelled distance over multiple sectors as described by SESAR concept of operations.

The expected benefits are threefold: (i) the ABM can be used to measure the optimization space. In the current scenario, it has demonstrated that moving to a business trajectory model is not only feasible but desirable in terms of overall optimization; (ii) the ABM can be used as a research tool, either as a common sandbox for different research programs (to make research easier to compare), or (iii) to provide synthetic data for data mining algorithms testing. The ELSA consortium decided to publish the ABM code as open-source, to facilitate the adoption by the research community.

ABM Strategic layer

The strategic layer of the Agent Based Model 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. Some sectors can also be randomly shut down after the first round of submissions, which triggers an additional round of negotiations. There are two versions of the model. The simplest version considers only the sector network and allows to perform extensive exploration of the interplay between the strategies of the air companies, the structure of departing waves, and the airspace geometry. The second version is more realistic and considers the navpoint network. It can be calibrated on real data.

The key parameter of the model is the satisfaction of the air companies, measured as a function of *punctuality* and *trajectory length*. The satisfaction is calculated by comparing the preferred flight plan and the accepted one for a given flight. This parameter can measure how much the system is able to satisfy air companies' demands.

One of the main result of the strategic layer is presented in Figure 4. It shows the satisfaction decrease when a specific sector is closed, forcing the air companies to submit a new flight plan for all those flight that were passing through that sector. The result gives a clear indication of how critical is each sector within a given airspace.

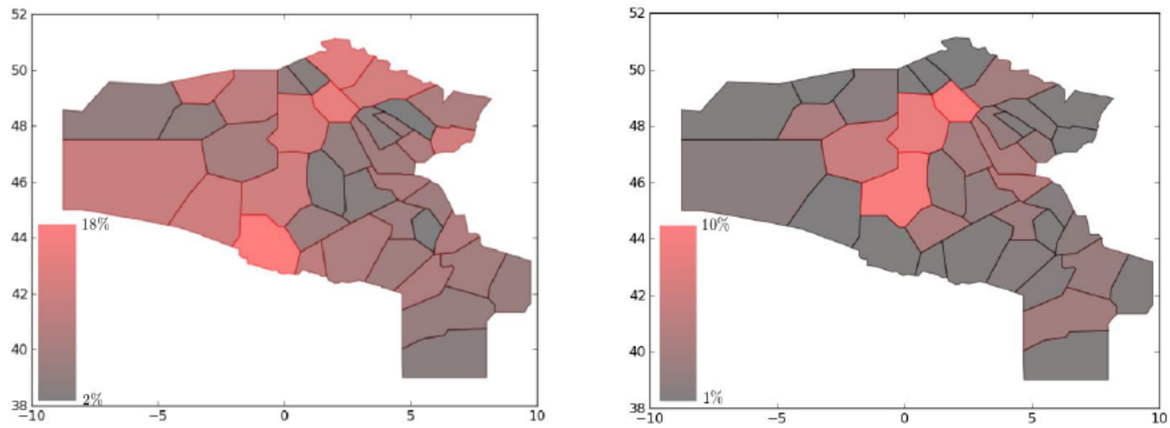


Figure 4: Drop of satisfaction of the whole system when a sector is closed. Left: satisfaction is computed on all flights. Right: satisfaction is restricted to flights which do not depart or arrive in the given sector.

The potential application of the strategic ABM is to test different optimisation strategies at the NOP level, for instance a more proactive NM, who actively negotiates trajectories to reach a global optimisation, rather than a flight-by-flight satisfaction. The ABM can also be used to simulate different patterns of departure waves, measuring the impact on the system on the different airlines. The strategic layer can also be used to feed flight plans to the tactical layer, tracing the impact of airlines' strategies on the tactical level, in terms of traffic complexity and required ATCOs' actions.

The main benefit of the strategic ABM is therefore the possibility of testing different management strategies for the overall network, both on the NM side and on the air companies side. The ABM can be used to detect in advance the most critical areas, i.e. those that have a major impact, if closed, on the satisfaction of the airspace users. It can then be used to test different strategies to offload them, measuring which is the "best one".

Decision Support Tool

The third ELSA outcome was the design and implementation of decision support tools, to (i) monitor the current complexity status, (ii) receive a prediction of the likely development, (iii) simulate the effects of changes to the system. The decision support tools was designed at the proof-for-concept level. This part of the work relied on a network of designers with experience from other domains, to bring new ideas and cross-fertilisation to ATM.

The target users had been selected as the Network Manager, the Complexity Manager, and the Flight Operation Centre, using the ELSA tools 24 hours prior departure (planning scenario), till during the flight execution (execution scenario). The following activities were addressed for each of them: identification of problems, definition and testing of solutions, negotiation. Following this work, the interface elements and the corresponding interaction modalities were designed.

ELSA designed two Decision Support Tools. (i) The "FlightLane" is the tool that supports Flight Operator Centre in managing the airline flights both in the planning and execution scenarios. (ii) The "Complexity Map" is the main tools for the Network Manager in the planning scenario and for the

Complexity Manager in the execution scenario. A snapshot of the complexity map is represented in the image below.

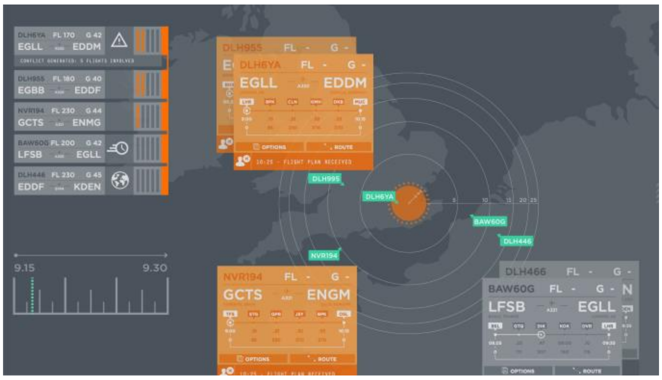


Figure 5. A snapshot from the Complexity Map.

Both tools are specialized views on a common set of data and information, as shown in the image below.

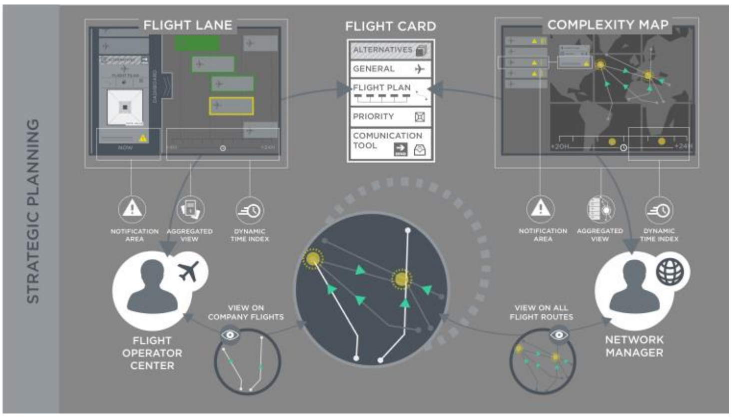


Figure 6. Overview of the proposed decision support tools for the strategic planning scenario.

The potential application of this strand of work would be to show the proposed concepts and visualisations to SESAR projects working on similar tools, i.e. Network Management tools. The core of the ELSA work went into information visualisation, so part of this work can also be used to visually communicate some SESAR concepts, showing their application in operational scenarios.

The main benefit for the ATM community of this part of the work lies in the interface design. The proposed scenarios were prepared to show how the target roles could visualise and interact with traffic in a SESAR scenario. The work is a visualisation of existing SESAR concepts, with details on the interface and tools to be used.

Conclusions

The main value delivered by ELSA to the SESAR community lies in the coordination of the data analysis part with the simulation of a future SESAR scenario. Three aspects are relevant.

First, ELSA developed several methods and tools to numerically describe the current ATM system at the EU level, but the same methods and tools can be used to measure the benefits brought by the implementation of SESAR concepts, e.g. integration of sectors in FABs, user-preferred trajectories. Such an extensive application of different analysis methods, together with rigorous validation, is a distinctive contribution to ATM research. Second, the ELSA simulation was calibrated on real data, both as input parameters (e.g. flight plans, aircraft speeds) and as end results (e.g. overall delay, number and types of re-routings). Third, although during the project the ELSA simulator did not reach a sufficient maturity in the current scenario to be extended to the SESAR one, it 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. All these simulations can be run by modifying key ingredients like user trajectories, airspace structure, ATM behaviour, to observe the resulting interactions and system-level dynamics.

1 Introduction

1.1 Purpose of the document

The purpose of this document is to:

- Summarise the technical results and conclusions of the project (Publishable Summary);
- Provide a complete overview of all deliverables;
- Provide a complete overview of all dissemination activities (past and in progress). Where appropriate, provide feedback from presentations. Describe exploitation plans.
- 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.

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, the project 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 24 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
ELSA	Empirically grounded agent based models for the future ATM scenario
FIR	Flight Information Region

Term	Definition
NM	Network Management
OCC	Operation Control Centre
SESAR	Single European Sky ATM Research Programme
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SNS	Scuola Normale Superiore of Pisa
STCA	Short Term Conflict Alert
TMA	Terminal Manoeuvring Area
UniPa	University of Palermo
WP	Work Package

2 Technical Project Deliverables

Number	Title	Short Description	Approval status
D5.1	1st Joint Event Review	This document contains the paper presented at SESAR Innovation Days, 29th Nov-1st Dec 2011. The title of the paper was "ELSA Project: Toward a complex network approach to ATM delays analysis" and described the preliminary results delivered by the project.	Approved
D1.1	Database of ATM indicators	This document describes a database of flight data originally stored in DDR and ASMT files and relative to flight trajectory data, safety events data and geographical sectors' data. It presents the structure of the database and discuss it by pointing out the interrelationships about flight information concerning airports, flight segments, sectors, dynamics of the air traffic management system, flight plans and realized flight trajectories. It also presents examples of several queries that can be performed with this database. Finally it discusses some examples of the use of the database for the investigation of statistical regularities of the ATM system and overlapping research areas and topics with other WPE research projects.	Approved
D1.2	Statistical Regularities in ATM - Draft	In this document we present the first part of the study of the statistical regularities. These regularities serve two purposes: firstly, to help qualitatively the design of the future Agent-Based Model (ABM) by selecting the proper entities, scales and relationships crucial for the system. Secondly, to have quantitative measures which will serve either as input to the Model or as validation tools. After the introduction sketching the general lines of the analysis, the second part is dedicated to the baseline, static analysis of several networks naturally present in the system (Airports, Routes, Navigation Points), studied in the framework of complex system science. The third and fourth parts focus on the difference between the planned 4D trajectories and the actual ones. Specifically, the third part deals with spatial deviation while the fourth one focuses on the time deviations, i.e. the delays. The last part of the report deals with the external shock the system underwent during the explosion of the Eyjafjallajokull in Iceland in April 2010. We study in this part how the system was affected and reacted to this massive stress by using the metrics introduced in the first part.	Approved
D1.3	Statistical Regularities in ATM	In this document we present our study of the statistical regularities in the ATM system. These regularities serve two purposes: firstly, to help qualitatively the design of the future Agent-Based Model (ABM) by selecting the proper entities, scales and relationships crucial for the system. Secondly, to have quantitative measures which will serve either as input to the Model or as validation tools. After the introduction sketching the general lines of the analysis, the second part is dedicated to the baseline, static analysis of the Airports and Navigation Points networks	Approved

		present in the system, seen from the perspective of the Complex System science. We consider here three time-scales: (i) we perform an analysis over different AIRACs to address long-term seasonality; (ii) we perform intra AIRAC analysis to address the existence of weekly patterns and (iii) in some case we perform intraday analyses to address the existence of intraday periodicities. The third, fourth and fifth parts of the report focus on the difference between the planned 4D trajectories and the actual ones. Specifically, we deal with spatial deviation in the third part while the fourth one focuses on the time deviations, i.e. the delays. The results of these two analyses are compared for different countries in the fifth part. A section of the report is also devoted to investigate the ATM system at the level of the ATC sectors. We investigate some basic features of the sectors infrastructure and some basic aspect of the flight trajectory management within sectors. The last part of the report deals with the external shock the system underwent during the explosion of the Eyjafjallajokull volcano in Iceland in April 2010. We study in this part how the ATM system was affected and reacted to this massive stress by using the metrics introduced in the first part. An exploratory analysis of safety data and their interrelation with flight trajectory data is also included in the final section of the report.	
D5.2	2nd Joint Event Review	This document contains the paper “Statistical Regularities in ATM: network properties, trajectory deviations and delays” presented at SESAR Innovation Days (SID), 27th 29th December 2012. The paper summarizes the results of the first year of the ELSA project.	Approved
D2.1	Prototype agent-based model	This deliverable describes the first steps toward a future two-layers Agent-Based Model (ABM) for the Air Traffic Management in the European airspace. The model itself is split in two parts, the Strategic layer and the Tactical layer, which aim to emulate the two main steps occurring in the ATM. For each part, the main characteristics of the system are first examined. Then, it is indicated which of them are planned to be included in the final version of the ABM and what is already implemented in the first versions of the model. It is also described in detail the first versions and the results obtained so far. Pseudo-code and flow-charts of the programs are also provided.	Approved
D3.1	Scenario Selection	This deliverable presents the progress of the work on the ELSA decision-support tool. It introduces the design process and method, the principles informing the tool, and a preliminary activity analysis. A benchmark from other domains is also included at the end of the document.	Approved
D4.1	Validation Plan	This deliverable presents the ELSA validation plan, detailing the objectives, the planned exercises, and the interactions between the validation Work Package and the technical Work Packages.	Approved
D5.4	Dissemination and external coordination	This deliverable reports all the dissemination activities accomplished within the project. Conference papers and presentations are enclosed.	Submitted
D2.2	Calibrated agent-based model -	The deliverable describes the advances made in the two layers of the model: Strategical and	Approved

	1st draft	Tactical. Specifically, the advances for the Strategical layer of the model mainly regard a better modelling of the different crossing times of each sector and the calibration of the model over a network of sectors whose features are taken from real data relative to the French airspace. Moreover, several metrics are introduced in order to the level of regulation of the airspace and the degree of satisfaction of individual air companies and of the aggregate of different air companies. For the Tactical layer of the model the main advances regard the implementation of a new de-conflcting module mainly based on the possibility that aircraft change velocity. This implementation is done by means of a genetic algorithm. The pseudo-codes of the two layers of the Agent-Based Model are also provided.	
D3.2	Static Decision Support Tool	This deliverable presents the progress of the work on the ELSA decision-support tool. It presents a short-list of concepts for the ELSA decision support tool. For each concept, we describe the main ideas, the design values behind, the support they may give to the various users, brief prototypical scenarios of use. The examples from other domains that were sources of inspiration are also summarised.	Approved
D4.2	Validation Report	This deliverable contains the first ELSA validation report, detailing the objectives, the exercises carried out and their outcomes.	Approved
D5.3	3rd Joint Event Review	This document contains the paper and slides presented at SESAR Innovation Days, 26th-28th of November 2013. The title of the paper is “An Agent Based Model of Air Traffic Management”. It summarizes the results of the Agent Based Model developed as part of the ELSA project	Approved
D2.3	Calibrated agent-based model - final version	This document describes the Agent-Based Model developed within the project. The model is composed of two distinct layers: the strategic layer, simulating the interaction between the Network Manager and the Airline Operators and the tactical layer, focused on aircraft and controllers' behavior in a single Air Traffic Control (ATC) sector.	Submitted
D3.3	Validated Decision Support Tool	This deliverable presents the final concepts of the ELSA decision-support tool. For each concept, we describe the main ideas, the design values behind, the decision support they offer. Images of the tools and of the corresponding interaction modalities are also given. Scenarios of use are represented in a storyboard format.	Submitted
D4.3	Final Validation Report	This deliverable contains the ELSA final validation report, detailing the objectives, the exercises carried out and their outcomes.	Submitted
D5.5	Final workshop	This deliverable contains the materials used for the project final workshop and for all the final dissemination presentations.	Submitted

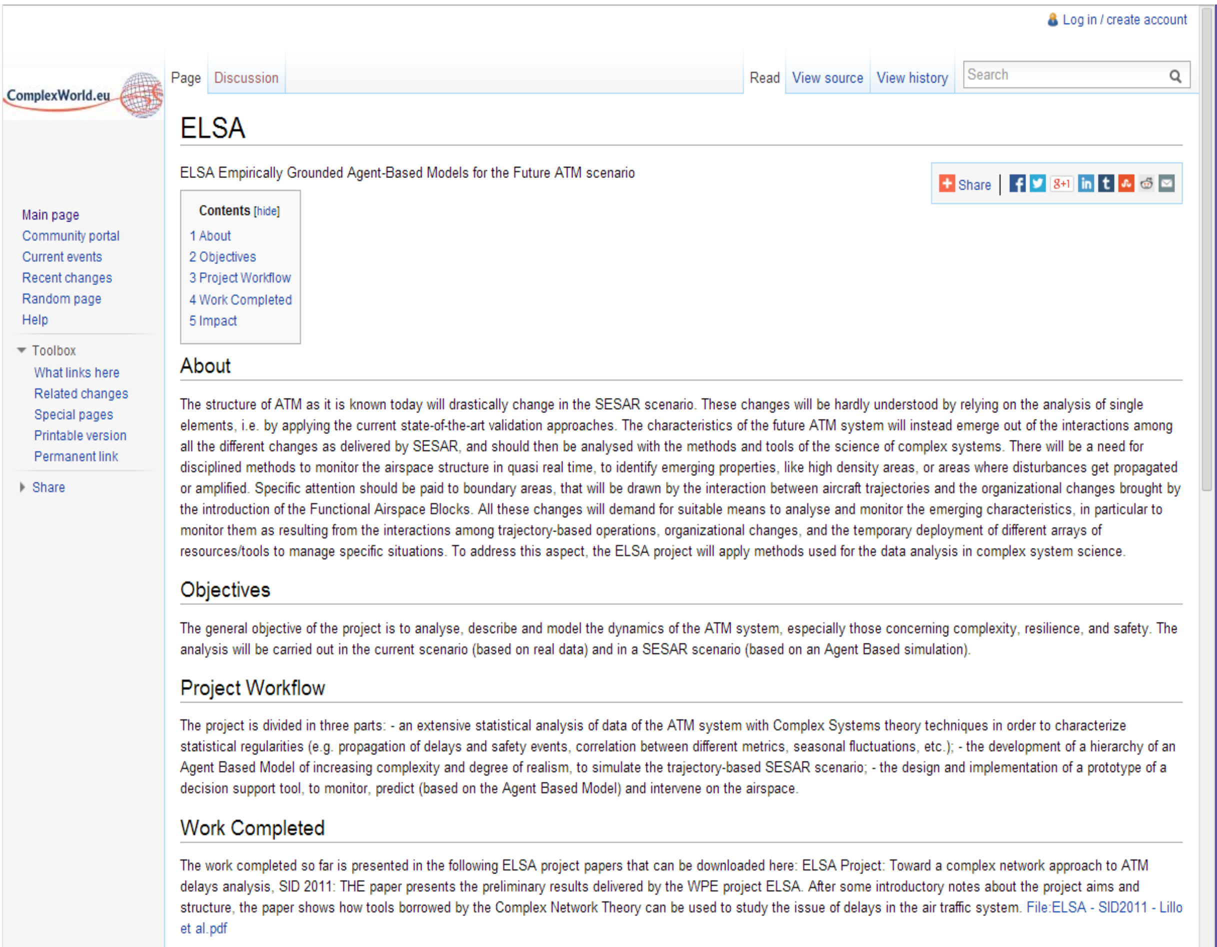
Table 1 - List of Project Deliverables

3 Dissemination Activities

The work done during the ELSA project has regularly being submitted to various conferences and events associated to various communities. Articles presenting the work done in the ELSA project have been submitted each year to the SESAR innovation days and to ATOS conference. Also, the project periodically updates its wiki page on the Compex World website to disseminate towards the general public and the Complex World Network. Dissemination and exploitation actions were also carried out by exploiting personal contacts and other projects' meetings.

3.1 Dissemination towards General public and Complex World Research Network

The ELSA Project wiki page is available at the following address: http://complexworld.eu/wiki/ELSA The website is updated with information about ELSA project activities and productions, including the list of research papers.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ELSA

ELSA Empirically Grounded Agent-Based Models for the Future ATM scenario

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About

The structure of ATM as it is known today will drastically change in the SESAR scenario. These changes will be hardly understood by relying on the analysis of single elements, i.e. by applying the current state-of-the-art validation approaches. The characteristics of the future ATM system will instead emerge out of the interactions among all the different changes as delivered by SESAR, and should then be analysed with the methods and tools of the science of complex systems. There will be a need for disciplined methods to monitor the airspace structure in quasi real time, to identify emerging properties, like high density areas, or areas where disturbances get propagated or amplified. Specific attention should be paid to boundary areas, that will be drawn by the interaction between aircraft trajectories and the organizational changes brought by the introduction of the Functional Airspace Blocks. All these changes will demand for suitable means to analyse and monitor the emerging characteristics, in particular to monitor them as resulting from the interactions among trajectory-based operations, organizational changes, and the temporary deployment of different arrays of resources/tools to manage specific situations. To address this aspect, the ELSA project will apply methods used for the data analysis in complex system science.

Objectives

The general objective of the project is to analyse, describe and model the dynamics of the ATM system, especially those concerning complexity, resilience, and safety. The analysis will be carried out in the current scenario (based on real data) and in a SESAR scenario (based on an Agent Based simulation).

Project Workflow

The project is divided in three parts: - an extensive statistical analysis of data of the ATM system with Complex Systems theory techniques in order to characterize statistical regularities (e.g. propagation of delays and safety events, correlation between different metrics, seasonal fluctuations, etc.); - the development of a hierarchy of an Agent Based Model of increasing complexity and degree of realism, to simulate the trajectory-based SESAR scenario; - the design and implementation of a prototype of a decision support tool, to monitor, predict (based on the Agent Based Model) and intervene on the airspace.

Work Completed

The work completed so far is presented in the following ELSA project papers that can be downloaded here: ELSA Project: Toward a complex network approach to ATM delays analysis, SID 2011: THE paper presents the preliminary results delivered by the WPE project ELSA. After some introductory notes about the project aims and structure, the paper shows how tools borrowed by the Complex Network Theory can be used to study the issue of delays in the air traffic system. File:ELSA - SID2011 - Lillo et al.pdf

Figure 7: ELSA wiki page – Complex World

3.2 Dissemination towards the ATM public

ELSA results have been presented in various occasions to the following audiences:

- ANSPs Safety Managers and Safety Experts,

- ENAV Safety Unit,
- Members of FABEC, in IANS Luxembourg
- MUAC Safety Group and Trainers.

3.3 Presentations at SESAR innovation days (SESAR community)

SESAR innovation days have been an opportunity to present to the SESAR community the on-going work and the achievements of the ELSA project.

3.3.1 SESAR Innovation Days, Stockholm, Sweden, November 26-28, 2013

For SID 2013, the ELSA project members submitted a paper entitled "An Agent Based Model of Air Traffic Management"[1]. The contribution describes the structure of the two layers of the Agent Based Model developed within ELSA and gives an overview of the main results.

3.3.2 SESAR Innovation Days, Braunschweig, Germany, November 27-29, 2012

For SID 2012, the ELSA project members submitted a paper entitled: "Statistical Regularities in ATM: network properties, trajectory deviations and delays"[2]. The paper summarizes the results of the first year of the ELSA project. We performed a network study of the air traffic infrastructure starting from the airports and then refining our analysis at the level of navigation points, in order to understand what are the main features that may help explaining why some nodes of the network happen to be found in the same community, i.e. cluster. In a second investigation we performed a study at the level of flight trajectories with the aim of identify statistical regularities in the spatio-temporal deviations of flights between their planned and actual 4D trajectories.

3.3.3 SESAR Innovation Days, Toulouse, France, 29 November – 2 December, 2011

For SID 2011, the ELSA project members submitted a paper entitled: "ELSA Project: Toward a complex network approach to ATM delays analysis"[3]. This paper shows how tools borrowed by the Complex Network Theory can be used to study the issue of delays in the air traffic system. It also reports the preliminary results delivered by the project.

3.4 Presentation at other ATM conferences

3.4.1 4th International Air Transport and Operations Symposium (ATOS), Toulouse, France, July 8-10, 2013

For ATOS 2013, the ELSA project members submitted a paper entitled: "Exploratory analysis of safety data and their interrelation with flight trajectories and network metrics"[4]. This paper presents an exploratory analysis of the correlation between different network metrics and safety events. The objective is to develop analysis methods and indicators that relate the network structure with safety events. In particular by using data gathered with an automatic tool developed by EUROCONTROL and a database of traffic data, the authors measured the correlations between the classical metrics of the airspace network, especially the network of navigation points, and the occurrence of Short Term Conflicts Alerts (STCA). The results obtained are not univocal; correlation between STCA occurrences and classical network metrics are present but the correlation coefficient is around 0.7. This indicates that correlation between STCA occurrences and the airspace characteristics can be established but further analyses with more data are necessary to confirm this result.

3.4.2 3rd International Air Transport and Operations Symposium (ATOS), Delft, Netherlands, June 18-20, 2012

For ATOS 2012 the ELSA project members showed a presentation entitled "BIG DATA IN ATM: Lesson Learnt from the ELSA Project". The presentation described the approach adopted by ELSA in order to exploit successfully the huge amount of data available to develop useful solutions for the ATM world.

3.4.3 1st Complex World Annual Conference, Seville, Spain, July 8-11, 2011

For the 1st Complex World Annual Conference the ELSA project members showed a presentation about how the ELSA project dealt with resilience in the ATM system. The presentation gave an overview of the project and described the research direction taken by ELSA in the analysis of ATM resilience.

3.5 Presentations/publications at other conferences/journals

3.5.1 European Conference on Complex Systems (ECCS), Barcelona, Spain, September 16-20, 2013

For ECCS 2013, the ELSA project members submitted an abstract entitled: "An Agent Based Model of the Air Traffic Management"[5]. The conference presentation described the characteristics of the Agent Based Model developed within ELSA by detailing the agents involved and the way the interact with each other. Moreover results of the preliminary simulations were also presented.

3.5.2 European Conference on Complex Systems (ECCS), Bruxelles, Belgium, September 3-7, 2012

For ECCS 2012, the ELSA project members submitted an abstract entitled: "How the ATM System modifies in presence of extreme exogenous events: the special case of the Iceland Volcano eruption."[6] The presentation was about the analysis of the modifications induced in the ATM system network by the ash cloud that spread over Europe in April 2010. By using the Complex Systems tools the authors showed how the system reacted in terms of number of active flights and airports and in terms of the reshaping of airport and sectors communities.

3.6 Publications on other journals

The ELSA team members submitted a paper entitled "Multi-scale analysis of the European airspace using network community detection" to the scientific journal PLOS ONE [7]. The paper has been accepted and the final version is currently being prepared. In this work, we analyse the European airspace as a multi-scale traffic network whose nodes are airports, sectors, or navigation points and links are defined and weighted according to the traffic of flights between the nodes. By using the ELSA database of the air traffic in the European airspace, they investigate the architecture of these networks with a special emphasis on their community structure. The paper proposes that unsupervised network community detection algorithms can be used to monitor the current use of the airspace and improve it by guiding the design of new ones. Specifically, the authors compared the performance of three community detection algorithms, also by using a null model which takes into account the spatial distance between nodes, and they discuss their ability to find communities that could be used to define new control units of the airspace.

3.7 Demonstrations

The following two demonstrators have been developed during the project:

1. Demonstrator of the ABM tactical layer to show a real-time simulation of the air traffic within a sector

2. Demonstrator of the Decision Support Tool to show all the functionalities of the proposed concept.

ABM demonstrator

In order to show in an easier and more understandable way the outputs of the tactical layer of the ABM, it was developed a graphic simulator of the air traffic within the considered sector. The ABM Demonstrator simulates the traffic in the sector of the Italian airspace LIRROV. The Demonstrator can simulate the deviation occurred to the aircraft trajectories to avoid conflicts and possible shocks that appears within the sector.

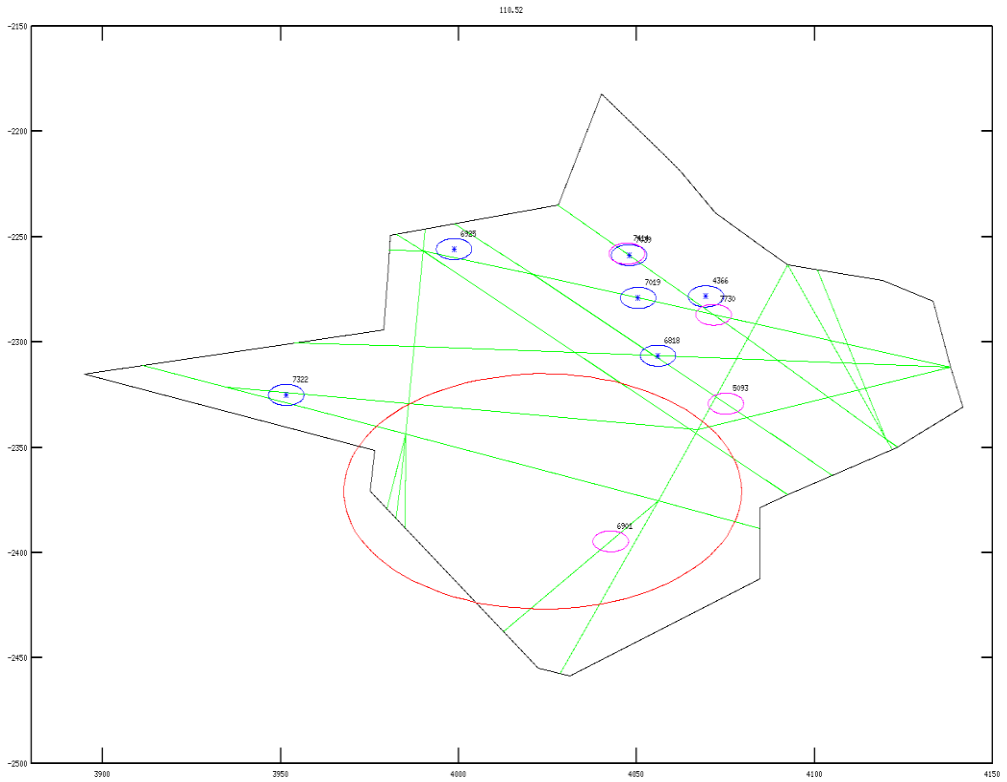

Figure 8: ABM demonstrator

The enclosed figure illustrates the Demonstrator interface. The blue dots are the aircraft, the circles around them represents the minimum separation of 5 NM. The green lines are the planned trajectories while the red circles represent the shocked areas. Shocks can occupy a single or multiple flight levels. This is why in the figure there is an aircraft crossing a shocked area.

During the exhibit at SESAR Innovation Days 2013 we showed different real-time examples of the ABM. We gathered a good feedback on the ability of the model to simulate the air traffic in presence of different shocks configurations and traffic loads.

Decision Support Tool Demonstrator

Two videos have been prepared to show the functionalities of each of the designed Decision Support Tool. The “Flight Lane” is the tool that supports Flight Operator Centre in managing the airline flights both in the planning and execution scenarios. The “Complexity Map” is the main tools for the Network Manager in the planning scenario and for the Complexity Manager in the execution scenario.

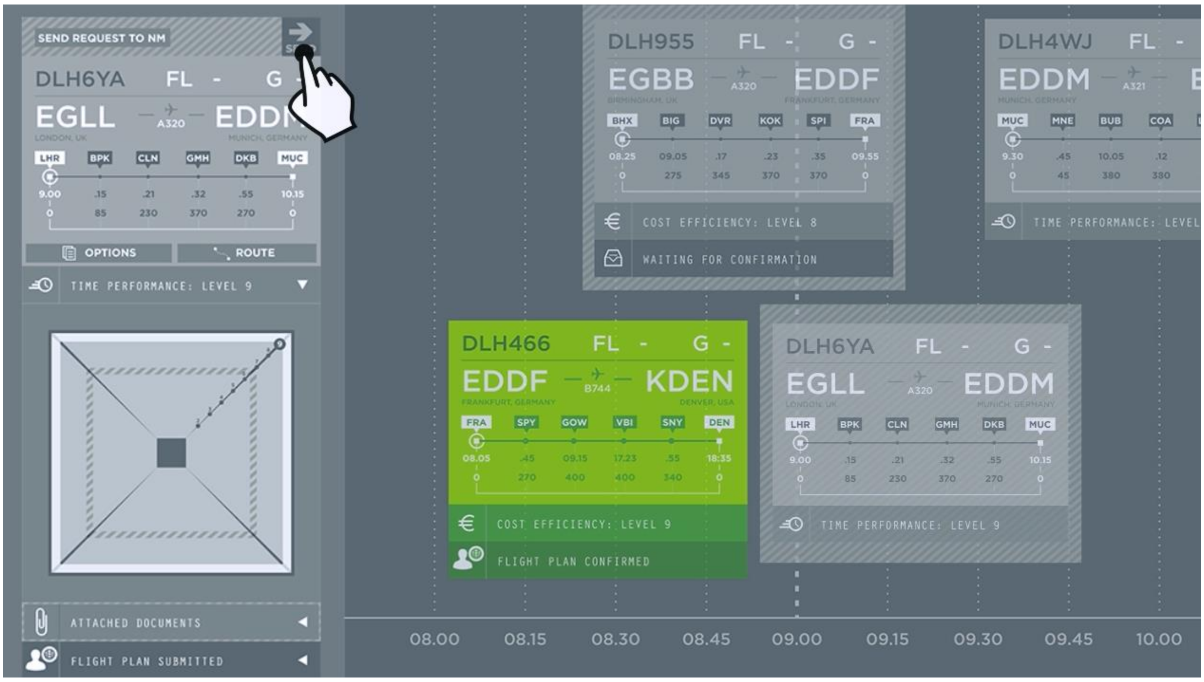

Figure 9: A snapshot of the demonstrator showing the "Flight Lane"

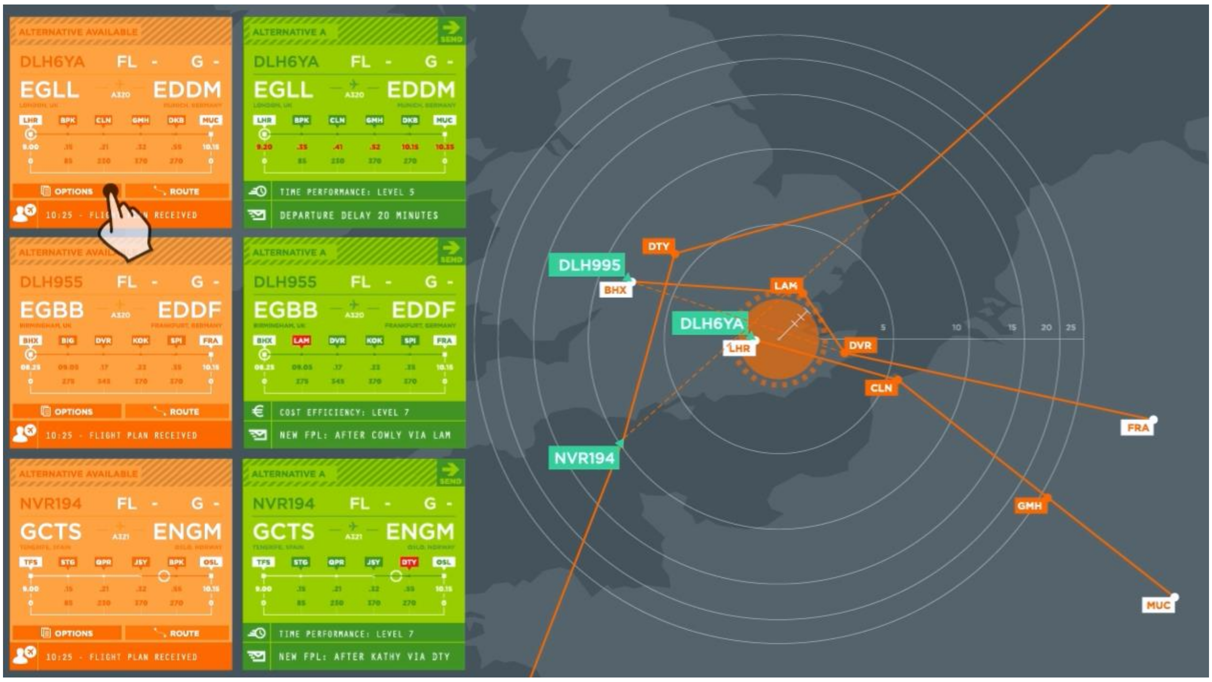

Figure 10: A snapshot of the demonstrator showing the "Complexity Map"

3.8 Exploitation plans

The results and lessons learnt from the ELSA project will benefit the Deep Blue Company and the research community (especially in the fields of Complex Systems and …).

3.8.1 Expected benefits for Deep Blue

The Company will transfer some of the proposed analyses (and the database developed to support them) into the following existing activities:

- SESAR Validation activities, in support to various SESAR projects, via ENAV,
- analysis of automatically collected safety data, via the ASMT activities of the EUROCONTROL Safety Unit.

This exploitation will require additional work to advance the level of maturity and to customise the analyses.

The WP3 results will be exploited in different research activities, to demonstrate the company capability of developing highly innovative concepts for safety critical systems. Current opportunities include two research projects on cockpit innovation.

In general, the ELSA results will be fed whenever possible into other R&D activities, including other SESAR WpE projects, in order to advance their maturity and make them exploitable at the market level. Example include the following projects: EXCROSS, ASCOS, PROSPERO, ProGA.

3.8.2 Expected benefits for the University of Palermo

The research unit at the University of Palermo has gained significant competence in two areas:

- Development, management, and use of complex database of large datasets,
- 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 could constitute the starting point for the preparation of new grant proposals on air traffic dynamics, socio-technical systems, and traffic systems.

3.8.3 Expected benefits for the University of Pisa

The research unit at the Scuola Normale di Pisa has gained significant competence in two areas:

- Development, management, and use of complex database of large datasets,
- Development of Agent Based Models and their calibration on real data.

These competences will be useful in many research activities of the group in Pisa, not only in the research on air traffic activities but also on other topics, such as finance and economics.

Moreover the competences and knowledge acquired with the ELSA project could be used for further empirical analyses, to identify new statistical regularities, and to advance the level of maturity of the ones already discovered.

Finally, the results of the ELSA project could constitute the starting point for the preparation of new grant proposals on air traffic dynamics, socio-technical systems, and traffic systems.

3.8.4 Expected benefits for the research community

ELSA delivered results on the application of complex network methods to the ATM world. The systematic tracing of the different analysis techniques that were followed represent a valuable lesson learnt, including the end result of a set of "bet analyses".

Among the tangible benefits for the research community, we can mention:

- the development of a database structure to support and speed up the analysis of ATM data,
- the definition of a set of relevant analyses for the ATM system,
- the development of a multi-layered agent-based model, that could be potentially extended or made more generic.

For the research community of interaction design, ELSA delivered three different concepts, including the future reference scenarios to be considered and the roles therein.

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
23/04/2012	D0.0, D0.1, D5.1. D0.2, D1.1	46.644,87 €	5.649,98 €	Paid
22/01/2013	D0.3, D1,2, D0.4, D0.5, D1.3, D5.2	113.270,68 €	13.435,27 €	Paid
08/08/2013	D0.6, D2.1, D3.1, D4.1	104.427,38 €	3.386,43 €	Paid
20/12/2013	D0.7, D2.2, D0.8, D3.2, D4.2	113.224,64 €	2.941,06 €	Paid
foreseen 05/03/2014	D0.9, D2.3, D5.3, D5.4, D5.5, D0.10, D3.3, D4.3	168.034,42 €	3.837,26 €	To be billed
GRAND TOTAL	574.852,00	545.602,00 €	29.250,00 €	

Table 2 Overview of Billing

Company	Planned man-days	Actual man-days	Total Cost	Total Contribution	Reason for Deviation
Deep Blue	894	880 (548 actual – last invoice missing)	237.702,58 tot actual cost of effort (invoice 1,2,3,4) Last invoice missing	178.276,94 euro (contribution for effort) Last invoice missing	No relevant deviation
University of Palermo	797	859 (574 actual – last invoice missing)	101.574,43 tot actual cost of effort (invoice 1,2,3,4) Last invoice missing	101.574,43 euro (contribution for effort) Last invoice missing	No relevant deviation
Scuola Normale Superiore di Pisa	869	887 (637 actual – last invoice missing)	97.716,21 tot actual cost of effort (invoice 1,2,3,4) Last invoice missing	97.716,21 euro (contribution for effort) Last invoice missing	No relevant deviation
GRAND TOTAL	2560	2686 (1759 actual – last invoice missing)	436.993,22 costs of total effort (invoice 1,2,3,4) Last invoice missing	377.567,58 euro (contribution for total effort) Last invoice missing	No relevant deviation

Table 3 Overview of Effort and Costs per project participant

5 Project Lessons Learnt

What worked well?
Reaction by the operational world, with constant feedback from a variety of stakeholders at the EU level (CODA group, Safety Unit), at the national level (ENAV, MUAC), at the industrial level (Alitalia). The project would be now in the position of setting up an Advisory Board. It provided valuable feedback for the refinement of the work.
Interdisciplinary collaboration between academic partners and the industrial partner, to ensure a good balance between highly innovative research and potential for application.
Cross-fertilisation from previous works by the academic partners, to speed up the research work.
Support received by the project officer (PO). It helped solve many problems finding the "best solution" (for the project). It provided valuable support in steering the research work towards concrete outcomes, both with general comments and with detailed suggestions.
Complementarity between the rigorous methods applied in the first WPs of the project and the interaction design WP. This last WP enabled the consortium to review all the results produced till that moment, to decide which could be used to feed a decision support system and better identify the added value of a data-driven approach as proposed by ELSA.
What should be improved?
The project started with little understanding and support on the available dataset. More than one year was invested in understanding data, before the actual work could begin. Top-down coordinated work with the other WpE projects dealing with data could have improved the process. Making a small dataset (e.g. one AIRAC) publicly available could help improving research on these data and also help other projects that will have to use them in the future. If the actual data could not be published a simulated dataset produced by our ABM could be used for the same purpose.
The payment upon delivery method is effective but it creates bureaucratic problems for the research entities. In the ELSA case, the post-doc positions could only start 5 months after the project KOM. No buffers were available in case of delays.
The payment upon delivery method forced the universities to create short-term positions (one year's duration). Such a duration is not attractive for candidates and caused a high turnover, as the selected candidates start searching for a new job after few months into the project. It would be better to recruit post-docs for positions of at least two-years in order to make these positions more attractive.
WP E project are funded at a rate of 75% of the full costs with the assumption that revenues from the research results can cover the rest of the participant costs. However, WP E projects have long term research aims and the results are mainly in terms of knowledge (hard to exploit). In addition, SESAR remains (usually) the foreground owner of the Deliverables produced. Horizon 2020 is adopting a different scheme: projects are funded 100% while reimbursement for overheads is reduced. This seems more in line with reality and would facilitate a lot the cost statement preparation and reimbursement process.

Contacts with the other SESAR projects (not WpE) are too limited. There is no access to the SESAR extranet. A workshop could be set up with SESAR projects representatives to ease dissemination towards them.
The deliverable structures could be made easier, in order not to divert resources from the research work. Preliminary deliverables could be more in the form of working documents. To tackle this issue, ELSA adopted an internal process of iteratively defining the outlines of the final deliverables, to focus the reporting work on high value elements.

Table 4 - Project Lessons Learnt

6 Support from external experts

We were supported by SJU air traffic controller [redacted]

We had one day meeting with him on the 27th January 2014.

Several further interactions took place via email, to refine WP3 scenarios.

7 References

[1] Bongiorno, C., Miccichè, M., Mantegna, R., Gurtner, G., Lillo, F., Valori, L., Ducci, M., Monechi, B., Pozzi, S. (2013) An Agent Based Model of Air Traffic Management, SESAR Innovation days, November, 2013.

[2] Vitali, S., Cipolla, M., Miccichè, M., Mantegna, R., Lillo, F., Gurtner, G., Pozzi, S., Beato, V. (2012) Statistical Regularities in ATM: network properties, trajectory deviations and delays, SESAR Innovation days, November 27, 2012.

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[4] B. Monechi, M. Ducci, M. Cipolla, S. Vitali, S. Micciché, R. N. Mantegna, G. Gurtner, F. Lillo, L.Valori, S. Pozzi (2013) Exploratory analysis of safety data and their interrelation with flight trajectories and network metrics, ATOS 2013.

[5] C. Bongiorno, G. Gurtner, L. Valori, F. Lillo, R. N. Mantegna, S. Miccichè, M. Ducci, B. Monechi, S. Pozzi (2013) An Agent Based Model of The Air Traffic Management, ECCS 2013.

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[7] G. Gurtner, S. Vitali, M. Cipolla, F. Lillo, R. N. Mantegna, S. Micciché, S. Pozzi (2013) Multi-scale analysis of the European airspace using network community detection, PLOS ONE (final version being prepared)