E-01.01- D42.1 – ComplexWorld Seminar and Tutorials: Report

Document information	
Project Title	ComplexWorld
Project Number	E-01.01
Project Manager	The INNAXIS Foundation and Research Institute
Deliverable Name	ComplexWorld Seminar and Tutorials: Report
Deliverable ID	D42.1
Edition	00.00.02
Template Version	03.00.00
Task contributors	
University of Seville; The INNAXIS Foundation and Research Institute	

Abstract

This report contains the summaries of the CW Seminar and Tutorials organized by the ComplexWorld Network during its fourth year of performance.

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Rejected By - *Representatives of the company involved in the project.*		
Name & Company	Position & Title	Date
<Name / Company>	<Position / Title>	<DD/MM/YYYY>

Rational for rejection
None.

Document History

Edition	Date	Status	Author	Justification
00.00.02	1/07/2014	Submitted	University of Seville and Innaxis	New Document

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This deliverable consists of SJU foreground.

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Executive summary

As part of its Research Coordination activities, in 2014 the Complex World Network has organized the following events:

- ComplexWorld Seminar, jointly with ICRAT2014,
- Tutorials Session, jointly with ICRAT2014.

The reports from these events are presented in this document.

1 Introduction

1.1 Purpose of the document

This document provides summaries of the Seminar and Tutorials organized by the ComplexWorld Network in 2014.

1.2 Intended readership

The target reader is any stakeholder in the ComplexWorld Network.

1.3 Acronyms and Terminology

Term	Definition
ATM	Air Traffic Management
CW	ComplexWorld
ICRAT	International Conference on Research in Air Transportation
SESAR	Single European Sky ATM Research Programme
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SJU Work Programme	The programme which addresses all activities of the SESAR Joint Undertaking Agency.
SESAR Programme	The programme which defines the Research and Development activities and Projects for the SJU.

2 ICRAT 2014

The SESAR's WP-E ComplexWorld Network has organized a Seminar and Tutorials as part of its Research Coordination activities, along with the 6th International Conference on Research in Air Transportation (ICRAT2014), held in Istanbul, Turkey, on May 26-30, 2014.

By decision of the organizers, the CW Seminar did not have a specific session devoted to it (likewise, the HALA! Network did not have a specific session for its ATACCS conference), but rather the several presentations related to complexity were scattered among the different tracks of the conference. In total, there were 7 presentations and also a keynote talk related to complexity. Note that there were a few presentations which included the word complexity in their titles or abstracts but they were not really within the scope of the CW Network, rather they referred to topics such as controller's workload.

The program of the presentations, tutorials and keynote talk is presented in the following table.

Table 1 Program of the CW Seminar and Tutorials

Tuesday, May 27, 2014	
Tutorial Session - Conference Hall #1	
10:00 - 12:00	Adverse Weather & ATM Performance (Thomas Hauf, LHU)
Track 1 - System Performance 1 - Conference Hall #1	
16:10 - 16:50	594 Sun - Topological Properties of the Air Navigation Route System using Complex Network Theory
16:50 - 17:30	615 Etxebarria - Data-driven Modelling of the Tree of Reactionary Delays
Wednesday, May 28, 2014	
Track 2 - Decision Support 3 - Conference Hall #2	
13:00 - 13:40	621 Casado - Analysis of the Impact of Intent Uncertainty on the Accuracy of Predicted Trajectories for Arrival Management Automation
Thursday, May 29, 2014	
Keynote talk - Conference Hall 1#	
08:45 - 09:45	Henk Blom, National Aerospace Laboratory (the Netherlands) and TU Delft, "In Search of Positive Emergent Behaviour of Air Traffic"
Tutorial Session - Conference Hall #2	
10:00 - 12:00	Data Science in Aviation: Stationarity and Metrics (Massimiliano Zanin & Samuel Cristobal, Innaxis)
Track 2 - Advanced Modelling 2 / Airport Design 1 - Conference Hall #2	
13:00 - 13:40	619 Ranieri - Assessing ATM Performance Interdependencies through Bayesian Networks

Track 3 - Network Management 3 - Conference Hall #3	
15:30 - 16:10	585 Walter - Quantifying Trajectory Uncertainty Using a Sensitivity-Based Complexity Metric Component
Friday, May 30, 2014	
Track 2 - Doctoral paper session - Conference Hall #3	
11:40 - 12:20	628 Kaya - A Dynamic Bayesian Belief Network Approach for Modelling the ATM Network Delays
14:50 - 15:30	623 Schwithal - Uncertainty Assessment for ETA prediction towards 4D Trajectory Operation

The CW Seminar (presentations and keynote talk) and Tutorials session are summarized in the following sections of this report.

3 CW Seminar

The keynote talk and the presentations related to complexity are summarized in the following subsections.

3.1 Keynote talk

In Search of Positive Emergent Behaviour of Air Traffic

Henk Blom
Delft University of Technology and NLR, Netherlands

Abstract: Air Traffic Management (ATM) forms a complex socio-technical system that involves dynamic interactions between a broad variety of distributed human decision makers, dynamical systems and environments. Some examples of such interactions are navigation systems supporting pilots, surveillance systems supporting controllers, changes in weather that may outdate flight plans, and communication between pilots and controllers. Over decades, this complex socio-technical ATM system has evolved to its current form in providing a very high level of safety. Growing demands in commercial air transport form the driver for the design and implementation of capacity increasing conceptual changes in this complex socio-technical ATM system. Because of the complex dynamic interactions, such changes may not only lead to the intended improvements, but may also lead to unforeseen emergent behaviours. Although emergent behaviours can be safety/capacity malevolent as well as safety/capacity benevolent, they tend to be of the former type as long as they are not well understood. Therefore novel ATM design can take great advantage from identifying and learning to understand safety/capacity relevant emergent behaviours during the early design. This talk explains how this is accomplished using complexity science techniques, including illustrative application to ATM designs.

An extended version of this talk was presented by the same speaker as a tutorial with the title "Using Complexity Science in Analyzing Safety/Capacity of ATM Designs".

3.2 Presentations

1. Topological Properties of the Air Navigation Route System using Complex Network Theory

Xiaoqian Sun[a], Sebastian Wandelt[b], and Florian Linke[a]
[a] Institute of Air Transportation Systems, German Aerospace Center, Blohmstrasse 18, 21079, Hamburg, Germany
[b] Department of Computer Science, Humboldt-University Berlin, Unter den Linden 6, 10099, Berlin, Germany

Abstract — Air Traffic Management (ATM) is the dynamic, integrated management of traffic in airspace. As aircraft fly through the sky, they follow pre-planned routes, much like highways on the ground. In order to meet the increased demand of air traffic, the structure of the airspace must be continuously analyzed and adapted. The planning of an airspace offering the required level of safety, capacity, flexibility, responsiveness, and environmental performance, is a challenging task. In this research, we, for the first time, analyze the air navigation route system of fifteen different countries from a consistent worldwide airspace database and compare these airspace structures using complex network theory. We investigate the following five metrics: degree, distance strength, weighted betweenness centrality, weighted closeness centrality, and edge length distribution. For each metric, we perform regression analysis in order to identify abstract, complex network patterns holding for each of the countries. We find that air navigation route networks for all fifteen countries are rather heterogeneous. Furthermore, we discover that the degree distribution for all countries is better fitted by tetration, instead of an exponential function, as believed in previous work on single countries. Analysis of weighted betweenness centrality shows that some countries (e.g. USA) are robust against random or targeted node failures; while other countries (e.g. South Africa) are rather vulnerable. The

hierarchical clustering based on the regression coefficients shows that the countries with similar geographical features are clustered together. Our work is a contribution towards a safe and efficient operation of airspace.

2. Data-driven Modelling of the Tree of Reactionary Delays. The way primary delay disruptions are handled determines the extension and pattern of the knock-on effect

B.Campanelli[a], JJ. Ramasco[a], P. Fleurquin[a], VM.Eguíluz[a], I.Etxebarria[b], and A.Arranz[b]
[a] Instituto de Física Interdisciplinaria y Sistemas Complejos, Universidad de Las Islas Baleares, Palma de Mallorca, Spain
[b] Transport and ICT Directorate, Ingeniería de Sistemas para la Defensa de España, S.A., Madrid, Spain

Abstract — In spite of the relevance of Reactionary delays for air traffic performance, the research effort to understand the origin and handle this kind of delays is in practice limited. While being critically important due to its contribution to the total cost of delay, it is the primary cause which must be identified if effective action is to be taken. The SESAR WP-E project TREE (data driven modelling of network-wide extension of the tree of reactionary delays in ECAC area) aims at characterizing and forecasting the propagation of reactionary delays through European Network taking into account the influence of the aircraft, crew and passenger links. Thus, the project proposes the use of innovative modelling techniques to explore new solutions that are not currently addressed by previous works.

3. Analysis of the Impact of Intent Uncertainty on the Accuracy of Predicted Trajectories for Arrival Management Automation

Enrique Casado[a], Miguel Vilaplana[b], and Luis P. D'Alto[b]
[a] School of Aerospace Engineering, University of Glasgow, Scotland
[b] Boeing Research & Technology Europe, Madrid, Spain

Abstract — Accurate trajectory predictions are required for high efficient Air Traffic Management (ATM) procedures. However, this process is strongly affected by the knowledge of the actual performance of the aircraft, the real weather that will affect the flight and the knowledge about how the aircraft will be operated throughout the trajectory. In addition, all automation tools present some limitations which constrain the capability of reducing the errors between predicted and actual trajectories. This paper presents a process for reducing the impact of such limitations in the case of continuous descent approaches by using ADS-B tracks. This method aims at finding the aircraft intent which best fits the recorded flight data based on the restrictions of a selected trajectory prediction infrastructure. Based on this optimal aircraft intent, a sensitivity analysis of the impact of the intent uncertainties in the described descent procedures is also presented.

4. Assessing ATM Performance Interdependencies through Bayesian Networks

Andrada Bujor and Andrea Ranieri
Advanced Logistics Group (ALG)-Indra Business Consulting, Barcelona, Spain

Abstract — The Performance model proposed by this study represents an innovative approach to deal with performance assessment in Air Traffic Management (ATM). It is based on Bayesian Networks methodology, which presents several advantages but also some drawbacks as highlighted along the paper. We illustrate the main steps required for building the model and present a number of interesting results obtained. The contribution of the paper is twofold: it presents a new methodological approach to deal with a problem which is of strategic importance for Air Navigation Service Providers (ANSPs) and at the same time it provides insights on the interdependencies between factors

influencing performance. Both results are considered particularly important nowadays, due to the SES Performance Scheme and the transition stage between the first and second reference periods.

5. Quantifying Trajectory Uncertainty Using a Sensitivity-Based Complexity Metric Component

Leif Walter[a], Manuel Pusch[a], Florian Holzapfel[a], and Dave Knorr[b]
[a] Institute of Flight System Dynamics, Technical University of Munich, Garching, Germany
[b] Senior Representative FAA, Federal Aviation Administration, Paris, France

Abstract — Previous studies on complexity measures have focused on traffic density and the geometry of interacting flights to quantify the difficulty of a particular traffic situation. Within this paper, the strong correlation between trajectory uncertainty and controller workload is used to show that sector complexity is not primarily driven by geometric features, but rather by the quantity of uncertainty that a controller has to face. A complementary complexity component is introduced that can help quantify the amount of uncertainty and therefore improves the assessment of controller workload required to handle a given traffic situation. This complexity component is based on sensitivity analysis, where the magnitude of uncertainty is obtained by directly investigating the impact of parameter variations to the aircraft's predicted position ahead in time. Therefore, the quantification of uncertainty is based on the inherent dynamics of a given flight and its trajectory, rather than an assumed random error. Numerical results for simulations based on the BADA model and an aircraft intent formalization are presented to illustrate the potential benefit of quantifying traffic complexity by using sensitivity analysis. Furthermore, by following this approach, trajectory uncertainty from an air traffic controller's perspective for a particular flight may be quantified and estimations can be made as the predictability of trajectories improves with surveillance technologies and data sharing with the aircraft flight management system.

6. A Dynamic Bayesian Belief Network Approach for Modelling the ATM Network Delays

Yigit Bekir Kaya and Gokhan Inalhan
Department of Aeronautics and Astronautics, Istanbul Technical University, Istanbul, Turkey

Abstract — This paper presents a new model for predicting departure, en-route, and arrival delays simultaneously before departure as well as during the course of flight. The proposed model is a Dynamic Bayesian Belief Network (DBBN), considering temporal, operational, spatial (other delays at the same airport), traffic, and hidden variables. The model is used as high-level parameters for predicting delay states of a route more accurately. Real European flight information ALL_FT+ data set has been used for modelling the DBBN associated with network delays. It has been observed that as DBBN propagates its belief the accuracy of the predicted variable increases continuously. For the specific test case of MAD-BCN route, we show that arrival time can be predicted with 70% confidence and ±30 minute tolerance 3 hours before departure. This tolerance and confidence progressively decreases during all pre-flight and actual flight phases.

7. Uncertainty Assessment for ETA prediction towards 4D Trajectory Operation

Alexander Schwithal and Peter Hecker
Institute of Flight Guidance, Technische Universitaet Braunschweig, Braunschweig, 38108 Germany

Abstract — One concept in future air traffic management is 4D trajectory based operation (TBO) which aims at improving airspace capacity and decrease the environmental impact. In order to maintain separation and exploit the benefits of these 4D-trajectories, aircraft must stay within very small volumes around their negotiated reference track. As a preliminary step initial 4D trajectories are planned that define one explicit time constraint for a target waypoint, for example on the final approach segment. Real benefits for other stakeholder come into play if accurate predictions for the

Estimated Time of Arrival (ETA) at that waypoint can be provided together with a statistical measure for meeting the negotiated Required Time of Arrival (RTA) window. Given this uncertainty measure, other users can weight the ETA prediction for their purposes and for example include additional buffers only if necessary.

This paper analyzes the sensitivity of ETA predictions to uncertainties in the wind forecast for an exemplarily 4D approach in the Terminal Area (TA). It further outlines the necessary steps in order to understand the mitigating effect of closed-loop speed control on the ETA uncertainty prediction. The final goal is to extend the current definition of a typical aircraft state vector with a reliability measure for the ETA, expressed for example in form of a standard deviation. The latter shall not only consider current aircraft performance metrics but also take into account the mitigation options by closed-loop control in the background of ATC regulations.

4 Tutorials Session

Tutorial1

Title:	"Providing insight into how to apply data science in aviation: stationarity and metrics"
Speaker(s):	XXXXXXXXXXXXX and XXXXXXXXXXXXX
Entity:	Innaxis Research Institute
Length:	1h30minutes, plus break and question&answer: total 2h
Day	Thursday 29th,
Time:	10:00 am -12:00am
Speaker(s) short CV	**XXXXXXXXXXXXX** Researcher at Innaxis, graduated in Aeronautical Management at the Universidad Autónoma de Madrid. With more than 80 published peer-reviewed contributions in international conferences and journals, he has vast experience in complex systems research, both theoretical and applied, and in collaborating with scientists from all over the world. His main topics of interest are Complex Networks, Data Science and their application to several real-world problems, as with modelling and understanding the ATM system or mining complex data sets. **XXXXXXXXXXXXX** Samuel is currently a researcher at Innaxis, focused on stochastic modelling, as well as a PhD candidate at the Universität Wien. He holds a MSc in Advanced Mathematics and Applications (Universidad Autónoma of Madrid); a BCs (with honors) in Mathematics (Universidad Complutense de Madrid); and a BEng in Telecommunication Systems (Universidad Politécnica de Madrid). Samuel has a strong mathematical background and, as a researcher, he has vast experience in mathematical models, data management, simulation programming, and applied software. For the last five years, he has been conceiving mathematical models within several ETCL, SESAR, FP6 and FP7 funded projects.
Tutorial short description	The aviation sector gathers and stores a large amount of unstructured, heterogeneous data from different sources and of a diverse nature: safety data and reports, flight plans, navigation data, airport data, radar tracks, etc. From airlines to ANSPs or airports, the ability to collect information through different data sensors is growing exponentially. Nevertheless, how the different stakeholders take advantage of these data has not evolved so rapidly and there is still a large gap for improvement. In this talk, we will review two topics of relevance for the correct application of data analysis to air transport. The first one is "stationarity", *i.e.* the importance of analysing data sets with coherent characteristics in time and space. When the stationarity of the system under study cannot be guaranteed, the results obtained can be plagued with errors and inconsistencies: for instances, causality relationships may spuriously appear, not due to a real dynamical mechanism, but just as a consequence of changes in the system. This is especially relevant when trying to forecast the future behaviour of the system by means of historical data, as relationships between the past and the future are an essential ingredient. The second topic will cover metrics, with focus on representativeness and significance. We study how different metrics can be misleading when interpreting the results of an study and how providing a simple answer is not always possible. Practical examples from ongoing research projects will be provided, namely: passenger-centered metrics, delay propagation metrics and resilience metrics. Representativeness and significance of the metrics will also be discussed in the

	tutorial.

Tutorial 2:

Title:	**"Adverse Weather and ATM performance"**
Speaker(s):	XXXXXXXXXXXXX
Entity:	University of Hannover
Length:	1h30minutes (total 2h)
Day	Tuesday 27th,
Time:	10:15 am -12:15am
Speaker(s) short CV	**XXXXXXXXXXXXX** Worked at the German Aerospace and Research Agency for 15 years in airborne turbulence and cloud measurements and also in cloud modeling. Since 1998 professor for meteorology at the Leibniz University Hannover. Research fields are traffic meteorology, shower modeling, aircraft icing, weather impact on aviation and weather avoidance modeling.
Tutorial short description	The various atmospheric aviation hazards such as icing, thunderstorms, lightning, wake vortices, turbulence, fog, reduced visibility, snow and ice at the ground etc. will be presented and their impact on aircraft safety and efficiency will be discussed. Delay statistics and accident and incident analysis supplement the discussion. Methodological problems for the latter will be addressed. The relation between safety, efficiency and punctuality will be highlighted. Methods to mitigate the impact will be presented. Mitigation strategies include increased situation awareness, eg by more weather information in the cockpit, specific adverse weather nowcasts and forecasts, weather expert systems, multi-observational and modeling systems such as ITWS, and also weather avoidance modeling. Basic linear versus nonlinear weather effects on ATM performance will be discussed.

Some remarks:

- All the information of the tutorials (presentations, recordings and outcomes) is being kept in the wiki (CWW) corresponding page: http://complexworld.eu/wiki/Tutorials_2014
- The ICRAT tutorials were celebrated in parallel sessions: in the case of Massimiliano and Samuel (Data metrics, visualization and stationarity), it was the parallel session with the highest number of attendees. In fact the room was fully crowded, and the interaction level achieved between attendees and speakers is worth being highlighted.
- The audience in Thomas Hauf tutorial was also remarkable, and being hold in the main room and just after the key note speech helped getting also a noticeable number of attendees.
- The speakers selection and the integration of the tutorials from ComplexWorld within the ICRAT general programme required an extra managerial effort due to the geo-temporal constraints caused mostly by the location of the event. At the end, ICRAT committee brilliantly solved the complex puzzle in terms on what day/time to celebrate each session taking into account both speakers and rooms availability.

5 Conclusion

As in previous occasions, organizing the CW Seminar and tutorial sessions along with a major international conference has proven to be quite beneficial, because of the following points:

- ComplexWorld attendees have had additional access to a good number of presentations related to complexity and submitted to other tracks such as System performance, Decision support, Advanced modelling and Network management.

- It is increased the networking possibilities between researchers of different fields, and at the same time the collaboration between all SESAR-WPE stakeholders: PhDs, projects, ComplexWorld and HALA!

- ComplexWorld and CWW gained visibility in ATM stakeholders from all around the world (attendees came from US, Europe, Africa and Asia)

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