E.02.39 EMERGIA D0.9 Report Final Management Report

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Abstract

The final management report of the EMERGIA 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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This deliverable consists of foreground generated as a result of the activities conducted by NLR within the framework of the project and co-funded with NLR resources. The foreground is therefore, according to the project contract[1], owned by NLR.

[1] EUROCONTROL Contract reference 10-220719-C7, Part II General Conditions, Article II.8.

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Publishable Summary

Problem Statement

The SESAR concept of operations (ConOps) beyond 2020 (SESAR2020+) involves a series of changes relative to conventional Air Traffic Management (ATM). Central to these changes is Trajectory Based Operations (TBO), that stands for the paradigm shift that aircraft should fly according to agreed conflict free 4D trajectory plans which are made known to all actors involved as Reference Business Trajectories (RBT's). A big unknown in this paradigm shift is how everything works under various kinds of uncertainty, as a result of which one or more aircraft may not realize their RBT's. There are several categories of uncertainty (including unexpected disturbances) that cannot be totally avoided, such as: meteorological uncertainties; data related uncertainties; human related uncertainties; and technical systems related uncertainties.

In principle the SESAR2020+ ConOps has been designed to take care of these kinds of uncertainty through the possibility of revising 4D trajectory plans, and also to allow air traffic control to issue tactical flight instructions to pilots if the 4D planning in the TBO layer has run out of time. Although these tactical instructions are quite similar to the established way of working by an air traffic controller, there also are significant differences. For example, under SESAR2020+ an air traffic controller is also expected to handle significantly more aircraft in its sector. Therefore the SESAR2020+ ConOps also foresees dedicated tactical decision support tools for air traffic controllers. The key issue is how to optimize the socio-technical collaboration between the TBO layer and the tactical layer in order to manage air traffic most effectively while taking into account the various uncertainties.

In conventional ATM, medium-term planning is provided by the planning controller, flight crews and their Flight Management Systems (FMS), whereas the tactical loop is formed by the tactical controller and flight crews. Thanks to decades of evolutionary developments, the collaboration between these two layers has been optimized. For SESAR2020+ a similar optimization of the novel TBO layer with the tactical layer is needed. Because the collaboration between these layers involves dynamic interactions between human decision makers, technical support systems, aircraft evolution, weather and other uncertainties, the combined effects result in types of emergent behaviours that cannot be predicted from the sum of the elemental behaviours.

Approach and methodology

During large European research projects HYBRIDGE and iFly, innovative complexity science techniques have been developed and applied to the identification of performance and emergent behaviours of a future ATM ConOps. In order to understand and improve the emergent behaviours of SESAR2020+ at multiple time scales, the EMERGIA project will apply these innovative complexity science techniques.

Within iFly, these innovative complexity science techniques have been applied to the most advanced airborne self-separation ConOps, which is referred to as A3 ConOps. This A3 ConOps also makes use of TBO and tactical layers, though fully airborne. Within iFly it has been shown that the A3 TBO and tactical layers work so well together that this leads to very powerful positive emergent behaviours, even beyond expectations of the concept developers. The three positive emergent behaviours that have been identified for A3 are: 1) Tactical conflict resolution layer is working very well in combination with a TBO medium term resolution layer; 2) No need to use a buffer between TBO resolution minimum and separation minimum; and 3) Even under extremely high en-route traffic demands there are no phase transitions happening. As a result of these powerful positive emergent behaviours, the A3 ConOps can safely accommodate very high en route traffic demands.

EMERGIA addresses the question whether these powerful emergent behaviours can be maintained while moving the TBO and tactical layers to the ground, as is the case with SESAR2020+. This EMERGIA research was organized in three phases. The first phase aimed to develop a ground-based version of the A3 model (shortly referred to as A3G model), to compare this to the SESAR2020+ ConOps, and to use the innovative complexity science techniques to identify the emergent behaviours of this A3G model. The second phase aimed to compare these emergent behaviours to those identified for the A3 ConOps, and to study the possible improvement of the A3G model in case of significant difference in emergent behaviours. The third phase aimed to evaluate the improved A3G (iA3G) model on its emergent behaviours, again by applying the innovative complexity science techniques. These three phases and their outcomes have been reported in the following three reports:

- Emergent behaviour of simulation model, EMERGIA report D2.2, December 2014.
- On the proposed improvements of the A3G ConOps, EMERGIA report D3.1, March 2015.
- Emergent behaviour of improved simulation model, EMERGIA report D4.2, June 2016.

Highlights and key results

During the first phase of EMERGIA, the sub-systems of the TBO and tactical layers in the A3 ConOps have been moved from the air to the ground, and also the tactical and planning controllers have been inserted in the loop. During the development of this A3G ConOps some decisions had to be made regarding the specific procedures to be followed by the tactical and planning controllers. In order to anticipate a large increase of traffic demand, it was decided to use datalink and to replace the current practice of the tactical controller awaiting positive read-back by the pilots by a ground system based verification of FMS downlinked information. Subsequently the innovative complexity science techniques have been applied to evaluate this A3G ConOps.

The results obtained in the first phase clearly showed that in comparison to the A3 ConOps, the A3G ConOps performance is so disappointing that it even was not relevant to compare A3G emergent behaviours against those of A3. Instead, an independent design team directly used the simulation findings as triggering points for the development of significant improvements to the A3G ConOps. The key improvements identified are: i) Better ground adaptation of conflict resolution algorithms in TBO and tactical layers; ii) Tactical ATCo is no longer directly in the loop of passing tactical instructions to pilots; and iii) Prioritizing the uplinking of conflict resolution messages. This is referred to as improved A3G (iA3G) ConOps. Using the innovative complexity science methods, an agent-based simulation model of the iA3G ConOps has been developed and rare event MC simulations have been conducted. The results showed that the improvements make great sense, as a result of which the iA3G model performs much better than the A3G model.

However, iA3G does not perform as well as A3 does. This difference also shows at the level of the indentified emergent behaviours. In the iA3G model, the TBO and tactical layers are able to work well together under the requirement that there is a significant spacing buffer between TBO resolution minimum and separation minimum. Another important emergent behaviour difference is that in contrast with A3, for iA3G ATCo task load may form a serious cap on en route traffic capacity limits. Although these findings do not come as a surprise from a conventional ATM perspective, they do not match up with the powerful emergent behaviours identified for the A3 ConOps.

Finally, there also are potential negative emergent behaviours of A3 and iA3G in need of technical requirements. Regarding the dependability of technical systems, the central organization of iA3G is more demanding than the decentralized A3 model is. In particular, very high iA3G requirements apply to ATC ground system, to ADS-B ground receiver, to Airborne uplink receiver failures, and to simultaneous failures of airborne ADS-B transmitter and SSR transmitter; very low probabilities of frequency occupancy of ATC-uplink and ADS-B; and short ATC Uplink transmitter sending duration.

Future steps based on the outcomes of the project

Although the emergent behaviours of the iA3G model are not as positive as those of the A3 model, for very high en route traffic demands iA3G does not perform bad at all. Therefore the iA3G model can be used as a valuable reference point for the further research and development of the SESAR2020+ ConOps. Important issues to be addressed are the differences between SESAR2020+ and iA3G, such as traffic demand, aircraft equipage percentage; time horizons of TBO and tactical layers; conflict resolution support to ATCo; conflict management architecture; closed-loop versus open-loop in tactical conflict resolution; and roles of ATCo's and pilots.

With the current iA3G model it is possible to investigate many of these differences by simply changing the model parameter values (e.g. traffic demand, time horizons). For some other differences (e.g. aircraft equipage percentage) it will be needed to also change the iA3G simulation model. Complementary to this, the further development of the iA3G model itself also is relevant, e.g. to incorporate climbing and descending traffic in the agent-based safety risk assessment. Another valuable research direction is to conduct bias and uncertainty analysis; this requires the development of a significant extra factor in acceleration of the rare event MC simulations. A third direction of research is to evaluate operational concepts that are mixtures of ground-based and airborne self separation TBO.

Conclusion

In conclusion, the EMERGIA project has shown that the powerful emergent behaviours identified in the pure airborne A3 ConOps are lost in an advanced ground-based ConOps version. This is due to various extra air-ground communication activities that cannot be avoided when adopting a centralized ground-based TBO ConOps instead of the distributed A3 ConOps. However, one would expect that the burden from these extra air-ground communication activities would be compensated in some way by an advantage of making use of a centralized joint conflict resolution capability. The EMERGIA project has shown that the latter advantage is far smaller than the advantage of the distributed nature of the A3 ConOps.

Complementary to this unexpectedly less positive finding for ground-based TBO, the EMERGIA project has also shown that in the large design space of future ATM, an advanced ground-based TBO ConOps, referred to as iA3G, has been identified for which it has been shown that it has the potential to safely accommodate high en-route traffic demands. This makes the agent-based iA3G modelling and simulation environment of value for modelling and analysis of the SESAR2020+ ConOps.

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 technical project deliverables;
- Provide a complete overview of all dissemination activities (past and in progress), and to describe exploitation plans;
- Provide a complete overview of the billing status, eligible costs, planned and actual effort (incl. an explanation of the discrepancies);
- Give an overview of the lessons learnt at project level.

1.2 Intended readership

The target readers of the document are:

- ATM simulation and modelling experts, interested in the state of the art of modelling approaches applied to ATM.
- Complexity Science researchers, since EMERGIA applies innovative approaches from complexity science regarding the modelling and analysis of future Air Transport Scenario.
- SESAR Airspace User Group, they will find specific topics/phases where their support is required in the project.
- Members of SESAR WP-E network "Mastering Complex Systems Safely", interested in feedback about usability of a modelling approach integrating ideas from complexity science.
- ATM operational researchers and SESAR participants: they will found simulation feedback about innovative strategies potentially contributing to reach performance goals.
- Airlines and Airspace Users in general. The potential of the tool for becoming a decision making support mean for Airspace Users is a fact that needs to be analysed.

1.3 Inputs from other projects

This document leans upon previous work within EC projects HYBRIDGE and iFly regarding new complexity science methods, that have been documented in [HYBRIDGE D2.2, 2003], [HYBRIDGE D2.3, 2005], [HYBRIDGE D2.4, 2005], [HYBRIDGE D8.1, 2003], [HYBRIDGE D8.3, 2004], [HYBRIDGE D8.4, 2005], and [iFly D7.2g, 2011] and that have been applied to an advanced airborne self separation concept of operations (ConOps) [iFly D7.4, 2012].

1.4 Acronyms

4D	4 dimensional
a/c	aircraft
A3	Autonomous Aircraft Advanced
A3G	Autonomous Aircraft Advanced Ground
ADS-B	Automatic Dependent Surveillance-Broadcast
AIAA	American Institute of Aeronautics and Astronautics
ATC	Air Traffic Control
ATCo	Air Traffic Controller
ATIO	Aviation Technology, Integration, and Operations
ATM	Air Traffic Management
ConOps	Concept of Operations
FET	Future Emerging Technology
FMS	Flight Management System
iA3G	Improved A3G ConOps
ICRAT	International Conference on Research on Air Transportation
MC	Monte Carlo
MTCR	Medium Term Conflict Resolution
n.a.	not applicable
RBT	Reference Business Trajectory
SESAR	Single European Sky ATM Research
SSR	Secondary Surveillance Radar
SID	SESAR Innovation Days
TMA	Terminal Maneuvering Area
STCR	Short Term Conflict Resolution
TBO	Trajectory Based Operations
WP	Work Package

2 Technical Project Deliverables

Number	Title	Short Description	Approval status
D0.0	Project Plan & Web site	Project plan and web-site http://emergia.nlr.nl of the WP-E project EMERGIA.	Approved
D1.1	SID 2013 paper	"In search of positive emergent behaviour in Trajectory Based Operations"	Approved
D1.2	Alternative for SID 2014 paper	"Can ground-based separation accommodate very high en route traffic demand as well as advanced self-separation?"	Approved
D1.3	SID 2016 paper; SID 2015 alternative	Forthcoming	
D2.1	Draft Simulation Model	This report develops an agent-based Monte Carlo simulation model to capture the accident risk and the flight efficiency of a conservative version of the SESAR2020+ ConOps.	Approved
D2.2	Emergent Behaviour of Simulation Model	This report studies rare emergent behaviour of a ground-based future concept (A3G) that makes use of both a strategic TBO layer and a tactical resolution layer. Key challenges are identified that remain to resolved in order to safely accommodate very high traffic demands.	Approved
D3.1	Report on the proposed improvements to the A3G concept	This document describes the results of the process that has been followed to identify potential modifications to the A3G concept to improve its performance. Several brainstorm sessions and discussions with experts have been held.	Approved
D4.1	Improved Simulation Model	This report develops a agent-based simulation model (referred to as iA3G) of the improved ConOps, implements this into Monte Carlo simulation code, and systematically verifies this code on its proper working. The latter includes a verification that the iA3G model performs much better than the A3G model.	Approved
D4.2	Emergent Behaviour of Improved Simulation Model	This report evaluates the iA3G simulation model of the improved ground-based TBO ConOps, and compares it to a model of the advanced airborne self-separation TBO model for which remarkably positive results have been obtained through the iFly project.	Submitted

Table 1 - List of Project Deliverables

3 Dissemination Activities

3.1 Presentations/publications at ATM conferences/journals

The dissemination activities under this section have been to date:

- **Conference Paper (D1.1)** at the Third SESAR Innovations Days (November 2013, Stockholm) entitled "In search of positive emergent behaviour in Trajectory Based Operations". [Blom & Bakker, 2013], describing the EMERGIA project aimed to extend the powerful emergent behaviour identified within iFly to a future ground-based ATM concept of operations.
- **Keynote** at ICRAT2014 (May 2014, Istanbul) entitled "In search of positive emergent behaviour in ATM". [Blom, 2014]
- **Conference Paper** at ICRAT2014 (May 2014, Istanbul) entitled "Agent-based safety risk analysis of TBO in TMA" [Teuwen et al., 2014].
- **Journal Paper** in AIAA Journal of Aerospace Information Systems, entitled **"**Safety Evaluation of Advanced Self-Separation Under Very High En Route Traffic Demand" [Blom & Bakker, JAIS2015].
- **Conference Paper (D1.2)** at the AIAA ATIO conference (22-26 June 2015, Dallas, USA) entitled "Can ground-based separation accommodate very high en route traffic demand as well as advanced self-separation?" [Blom & Bakker, ATIO2015].
- Forthcoming **Conference paper (D1.3)** at the Sixth SESAR Innovations Days (December 2016).

3.2 Presentations/publications at other conferences/journals

n.a.

3.3 Demonstrations

n.a.

3.4 Exploitation plans

The plans for exploitation of the EMERGIA results obtained are:

- **Feedback of the EMERGIA results obtained to SESAR and NEXTGENs.** This will be realized along two directions: 1) Through the EMERGIA User Group participants; and 2) Through making use of other future opportunities, e.g. as a result of networking.
- **Further use of the iA3G simulation model**. This consists of three main threads: i) Conducting simulation studies for other scenarios; ii) Conducting additional sensitivity studies under very high traffic demand; and iii) Conducting simulation studies under SESAR2020+ traffic.
- **Further application of the approach to other future ATM ConOps.** Both the iFly and the EMERGIA results obtained confirm the unique capability of agent-based modelling and simulation approach regarding gaining novel insights of future ATM ConOps regarding key performance indicators like capacity, safety, flight efficiency and pilot and ATCo task loads.
- **Agent-based modelling and simulation prototyping environment**. Using the iFly and EMERGIA experiences for the development of prototyping environment of an agent-based

modelling and simulation capability. This development is done jointly with University of Ilmenau (Prof. Armin Zimmermann) and with Eurocontrol Bretigny (Nicolas Fota and Eric Perrin). For this purpose, recently an EC FET-Open proposal has been submitted, entitled PoESyS (Positive Emergance in safety-critical socio-technical System of Systems).

4 Total Eligible Costs

Date	Deliverables on Bill	Contribution for Effort	Contribution for Other Costs (specify)	Status
28/11/2013	D0.0, D0.1,D2.1	47,935 €	-	Paid
26/11/2014	D0.2-D0.3,D1.1,D2.2	51,714 €	-	Paid
24/03/2015	D0.4-D0.5,D3.1	56,622 €	413 € (gate + progress meetings Brussel)	Paid
30/03/2016	D0.6-D0.7,D1.2,D4.1	67,193 €	3510 € (Travel to AIAA conf. in Dallas, June 2015)	Paid
forthcoming	D0.8-D0.11,D3.1,D4.2	72,207 €	400 € (progress + closure meetings Brussel)	To be billed
GRAND TOTAL		295,671 €	4323 €	

Table 2 - Overview of Billing

Company	Planned man-days	Actual man-days	Total Cost (75%)	Total Contribution	Reason for Deviation
NLR	375	435 *	315,000 € *	299,994 €	Unexpected coding errors were identified and resolved during verification of the iA3G model.
GRAND TOTAL	375	*435 **	315,000 € *	299,994 €	

Table 3 – Overview of Effort and Costs per project participant (* = estimation)

5 Project Lessons Learnt

What worked well?
The **single-partner project** did not requiring great managerial workload, perfectly fitted the project size, objectives and technical challenges.
The project established **clear scope, objectives and plan** from the start. This provided a good framework for delivering concrete answers and conclusions.
The systematic approach followed in the **agent-based modelling and simulation of a future ATM ConOps** has shown to work well.
On the side of **project external supervision**, the communication with Eurocontrol and SESAR-JU worked very well.
The research results obtained by the EMERGIA project were unexpected**;** they provide **novel views** regarding ground-based TBO in future ATM ConOps as well as the role of MTCR and STCR algorithms.
What worked less well than expected?
Conducting agent-based modelling and simulation with support from Aerospace Engineering MSc students proved to work well regarding the conduction of MC simulations, though not so regarding the modification of the model and computer code.
The acceleration of the rare event MC simulations has to increase by two orders in magnitude.
By the end of the project there was no time left to organize a feedback session with SESAR2020+ experts.
Before the gate meeting the User Group partners were participating in progress meetings through telecon. Since the Gate meeting the meetings were no longer at NLR, and therefore this had been discontinued.

Table 4 - Project Lessons Learnt

6 References

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