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Final Project Report

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National Aerospace Laboratory NLR, VU University Amsterdam, University of L'Aquila.	

Abstract

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

Authoring & Approval

Prepared by - *Authors of the document.*		
Name & Company	Position & Title	Date
[redacted] NLR	[redacted]	7/10/2013
[redacted] VU		7/10/2013
[redacted] AQUI		7/10/2013

Reviewed by - *Reviewers internal to the project.*		
Name & Company	Position & Title	Date
[redacted]	[redacted]	30/09/2013

Approved for submission to the SJU by - *Representatives of the company involved in the project.*		
Name & Company	Position & Title	Date

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This deliverable consists of SJU foreground.

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Publishable Summary

The need for resilience in ATM

Resilience is important for the sociotechnical air traffic management (ATM) system, where large numbers of interacting human operators and technical systems, functioning in different organizations at a variety of locations, must control air traffic safely and efficiently in the context of uncertainty and disturbances (e.g. delays, weather, system malfunctioning). Although procedures and regulations tend to specify working processes in ATM to a considerable extent, the flexibility and system oversight by human operators are essential for efficient and safe operations in normal and rare conditions. The recognition of the positive contributions of human operators for maintaining safety in complex sociotechnical systems has been a main driver of the resilience engineering research field and it explains the focus on the relation between human factors and safety herein. Resilience engineering stresses the inevitability of performance variability of human operators to adjust to the demands and conditions in the working context. As such, resilience engineering emphasises much more the variety of potential ways of human operators to deal with nominal and non-nominal conditions in their effort to support safety, rather than adhering to human error based thinking, such as applied in traditional human reliability assessment and event sequence based accident models.

Objective of MAREA

For a sociotechnical system as complex as ATM, resilience engineering is at an early stage of development. During recent years, novel psychological model constructs have been studied in capturing human cognition and its interaction with other joint cognitive system entities. The MAREA partners recognised that there are non-psychological challenges for prospective analysis of resilience in complex systems, due to the combinatorially many potential behaviours that may stem from external and internal events and the subsequent interactions between the various entities in the joint cognitive system. As a way forward, the objective of MAREA has been to develop an adequate mathematical modelling and analysis approach for prospective analysis of resilience in ATM. Such key complementary approach is intended to support effective implementation of resilience engineering for a joint cognitive system as complex as ATM.

Database of hazards for the study of resilience

In the process of assuring the safety of air transport operations, the assessment of the risk implications of hazards in the operation considered plays a central role. Here a ‘hazard’ means any condition, event, or circumstance which could induce an accident. A prime means in gathering hazards for safety assessments is by brainstorm sessions with pilots, controllers and other experts. These hazard brainstorm sessions aim to push the boundary between functionally imaginable and functionally unimaginable hazards. Consequently, considerable parts of these hazard brainstorm sessions address human behaviour, conditions and interactions between humans and technical systems. As part of safety risk analyses conducted since 1995 for many proposed ATM changes, NLR has identified a broad range of related hazards. These hazards have been collected in a Hazard Database, which contains over 4000 hazards. Given the broad view on hazard identification and the systematic inclusion of human-related performance herein, we have set forth to use the hazards collected in the NLR ATM Hazard Database as a broad source of disturbances for the study of safety-related resilience in ATM. The NLR ATM Hazard Database has been analysed in order to select the unique hazards and to formulate them in a generalized way. This resulted in a total number of 525 generalized hazards as a basis for further study in MAREA. This total set of hazards was split into two similarly sized sets for a model identification and development phase, and for a validation phase.

Agent-based modelling for the study of resilience

An agent-oriented perspective is useful to conceptualise processes in complex sociotechnical systems, such as ATM. Agent-based modelling considers a sociotechnical system to be composed of several agents and the overall system behaviour emerges from the individual agent processes and their interactions. Agents in ATM operations (e.g. pilots, controllers, technical systems) can express a large variety of behavioural patterns and these are influenced by specific processes and characteristics

of the agent considered. Especially for human agents there is a wide range of cognitive and affective aspects that influence their behaviour. Such agent-related aspects can be represented by model constructs for each agent.

Library of agent-based model constructs

In MAREA a variety of agent-based model constructs have been identified that together can model a broad set of hazards in ATM. For each hazard considered, it was analysed which model construct or combination of model constructs could represent it. This was done by performing 'mental simulation', i.e. qualitative reasoning by a team of analysts about the way that the models can reflect a hazard. The result of such analysis is that a hazard can be well covered, partly covered or not covered by the model constructs. As part of the analysis, argumentation was provided about the mechanisms by which the models can cover a hazard, and the aspects that are yet missing. This analysis of the hazard modelling capabilities of model constructs was done in three phases.

- In the first phase, 13 model constructs were identified that have been used in the context of multi-agent dynamic risk modelling (MA-DRM) at NLR. Using these model constructs, 58% of the hazards could be modelled well, 11% could be partially modelled and 30% could not be modelled.
- In the second phase, 11 complementary model constructs were identified through searching human performance models that have been applied by the Agent Systems research group at VU University Amsterdam. Including this extension, 80% of the hazards could be well modelled, 7% could be partially modelled, and 14% could not be modelled.
- In the third phase, 14 additional model constructs were identified in the literature for the hazards that had not yet been fully modelled. Including these additional model constructs, 92% of the hazards could be well modelled, 6% could be partially modelled, and 2% could not be modelled.

Integration of agent-based model constructs

All model constructs in the library have been integrated at a conceptual level, thereby creating an overall picture of their interconnectivity. At the highest level this overview has been split up in two parts: one to describe the interplay of the internal model constructs of the human, and one for the interplay of the model constructs that belong to the environment.

The hazards occurring in a number of historic incident and accident scenarios have been analysed as a systematic approach towards formalisation of model constructs. Based on this overview, a subset of combinations of model constructs has been selected for further formalisation. The formalisation of the integration was first described by means of visualisations and explanations about the interactions between the variables in the different model constructs, and subsequently by expressing the related mathematical formulae.

Validation of the agent-based model constructs

The analysis of model constructs against hazards in the validation set pointed out that 92% of these hazards are well modelled by the considered combination of model constructs, 8% of the hazards are partly modelled, and 1% of the hazards are not modelled. These numbers are similar to the results found for the hazard dataset used in the model identification and development phase (92% well modelled, 6% partly modelled, 2% not modelled). This similarity shows that the library of model constructs is not biased towards the hazard set used in the model identification and development phase. The library of model constructs identified in MAREA is thus capable of modelling a large percentage of hazards in ATM.

As an additional means of validation, a selection of the model constructs has been used to develop a formal, executable model of an historic ATM scenario. This scenario addresses an aircraft descending below the minimal descent altitude because of impaired conditions of the flight crew members. The model consists of a formal integration of several model constructs from the library. Based on the integrated model, a number of simulations have been generated that describe ways in which hazards can evolve in this scenario.

As a third way to validate the agent-based model constructs, a series of interviews with ATM domain experts (air traffic controllers and pilots) were conducted. The main purpose of the interviews was to obtain feedback of the experts about the integrated model constructs' capability to model hazards in ATM scenarios and to describe variations in the evolution of such scenarios. This feedback has led to

a number of valuable insights. First, various conclusions have been formulated for the different (clusters of) model constructs separately. In general, these conclusions confirmed that our selection of model constructs was judged plausible by the experts. In addition, they indicated possible modifications that could be applied to make the model constructs more plausible. Secondly, several suggestions for potential new model constructs were presented. Finally, the interviewees provided useful feedback about the research methodology in general. This feedback illustrated that the experts' general attitude towards the proposed approach was positive. It was recognized that for adequate modelling of ATM operations, techniques are needed that can well capture the dynamics, variability and interactions of the relevant agents and processes.

Arena of Hybrid Systems for analysis of Critical Observability in ATM operations

A compositional framework termed Arena of Hybrid Systems (AHS) has been developed and applied to critical observability in ATM operations. Critical observability is a structural property of a hybrid system, which expresses the possibility to detect whether the system state is in a set of critical states, which may represent unsafe, unallowed or non-nominal situations. If a hybrid system enjoys this property, a hybrid observer can be constructed, which detects whether the hybrid system is in a critical state or not. The approach has been applied to a particular Terminal Manoeuvring Area (TMA) T1 operation and conclusions have been achieved for the following subjects.

Arena of Hybrid Systems (AHS). This compositional framework for hybrid systems has been shown to be effective in:

- Properly addressing heterogeneity of different actors – It appears that technical devices and procedures of human agents can be well modelled by finite state machines, and the dynamics of aircraft are better modelled by differential equations. The Hybrid Systems (HS) paradigm is general enough to capture the heterogeneous dynamics in the TMA T1 scenario.
- Properly capturing interaction among actors – The AHS paradigm permits to capture the exchange of both "continuous signals"-type information (e.g. position and velocity of the aircraft) as well as "digital signals"-type information (e.g. signals shared between the Cockpit HMI and ATM systems) among the agents involved.
- Properly capturing evolution of agents both in nominal and non-nominal operating modes – Mathematical models could be developed on the basis of model constructs in the model library and for hazards in the hazard database.

Critical Observability. When one or more agents in the TMA T1 operation are in non-nominal operating modes, possible safety critical situations may arise. It is therefore important to detect non-nominal operating modes, so that automatic and/or manual recovery from these situations can be processed. Critical observability has been shown to be effective in properly capturing which safety critical situation can be detected and which cannot.

Critical Compositional Bisimulation. Analysis of critical observability of the TMA T1 operation is complicated by the large number of variables involved, and therefore complexity reduction techniques were needed. Central for this is the notion of critical compositional bisimulation, which clusters agents that can be considered equivalent in the scenario. This procedure allows partitioning the set of agents into subsets, each one composed by equivalent agents.

Applying the MAREA results for analysis of safety-focused resilience

The MAREA project identified a set of 25 model constructs, which complement an existing set of 13 model constructs in MA-DRM. The additional model constructs include a variety of human, environmental and organization related model constructs, e.g. Operator functional state, Trust, Situation awareness with complex beliefs, Bad weather, and Formal organisation. This additional set of model constructs entails a larger variety in psychological and organisational factors, which supports the analysis of resilience in complex sociotechnical systems. By including such additional model constructs in the agent-based models of MA-DRM based safety assessments, a larger set of hazards can be represented in a direct manner. This implies that the emergent effects of the interactions between the model constructs used in the agent-based model can be directly reflected in Monte Carlo simulation results.

Agent-based modelling and simulation has considerable advantages over traditional probabilistic risk assessment (PRA) and human reliability assessment (HRA) approaches. In particular, the broad set of model constructs identified in MAREA supports direct representation of a wide variety of hazards in the ATM sociotechnical system by agent-based modelling, which can at best be represented indirectly by error/failure probabilities and error producing condition factors in traditional PRA/HRA. Due to the detailed agent-based modelling in MA-DRM, the behaviour of the interacting agents changes in response to encountered hazards/disturbances. Analysis of the implications of such changed behaviour in the agent-based model thus provides insight in the level of resilience of the ATM sociotechnical system.

A follow-up question is how the MAREA improved view of agent-based hazard modelling can be exploited effectively in agent-based safety risk assessment. Since a straightforward inclusion of all 25 complementary model constructs in the MA-DRM approach would lead to a further extension of the agent-based model of the ATM operation considered, a minimal modelling approach has been proposed. In this approach, for model constructs that have similar interaction based behaviour effects, the main one is included explicitly in the agent-based model, while the effects of the remaining model constructs are taken into account through bias and uncertainty assessment.

Conclusion

In conclusion, the MAREA project has demonstrated that a mathematical approach towards resilience engineering provides novel methods for prospective analysis of safety implications of resilience in ATM, which are complementary to already on-going resilience engineering developments. In the light of the shown practical feasibility of MA-DRM for safety assessment of air transport operations, we expect that the MAREA enhanced set of agent-based model constructs can further support the analysis of safety-relevant relations in the ATM sociotechnical system. In this way, resilience in ATM can be supported, thereby improving the ability of the ATM sociotechnical system to adjust to disturbances/hazards and sustaining safe operations. In future research we plan to apply the enhanced model set in detailed assessments of resilience in ATM.

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

Intended readership is for experts in resilience and safety risk modelling.

1.3 Inputs from other projects

The model constructs identified in MAREA have been developed in a range of earlier studies at NLR and VU University Amsterdam, including the EC FP5 OPAL project and the EC FP6 RESET project. The compositional framework Arena of Hybrid Systems and analysis of critical observability builds on previous research at University of L'Aquila, including the EC FP5 Hybridge project and the EC FP6 i-Fly project.

2 Technical Project Deliverables

Number	Title	Short Description	Approval status
D1.1	Hazards in ATM: model constructs, coverage and human responses (draft)	This draft report provides a basis for the development of a new mathematical modelling and analysis approach, by identifying model constructs that have been applied in ATM safety assessment, by identifying a broad set of ATM hazards, by studying the coverage of hazards by existing model constructs and by describing the way that controllers deal with hazards in their normal work.	Accepted
D1.2	Hazards in ATM: model constructs, coverage and human responses	This report provides a basis for the development of a new mathematical modelling and analysis approach, by identifying model constructs that have been applied in ATM safety assessment, by identifying a broad set of ATM hazards, by studying the coverage of hazards by existing model constructs and by describing the way that controllers deal with hazards in their normal work.	Accepted
D2.1	Library of existing VU model constructs	Existing accident risk assessment methods for ATM cover a certain percentage of the hazards that may potentially occur within air traffic operations. To significantly increase the percentage of hazards covered, work package WP2.1 explores to what extent existing agent-based model constructs, which originally have been developed for other purposes, can be used to represent hazards within air traffic operations. The focus is on model constructs developed by VU, mainly addressing human factors and interaction between multiple (human and computer) agents within teams.	Accepted
D2.2	New model constructs for hazard coverage	Existing accident risk assessment methods for ATM cover a certain percentage of the hazards that may potentially occur within air traffic operations. The purpose is to increase the percentage of hazards covered by exploring various types of agent-based model constructs. In this deliverable, a number of novel model constructs have been developed (at a conceptual level), in order to cover some of the hazards which were still uncovered based on the analysis from D2.1.	Accepted
D2.3	Draft formal specification of model constructs	In previous research, a library of agent-based model constructs has been established. In this draft report, a selection of these model constructs are integrated and first steps towards their formalisation are made.	Accepted
D2.4	Formal specification of model constructs	In previous research, a library of agent-based model constructs has been established. In this report, these model constructs are integrated into a large multi-agent model, and a selected subset of the mode has been formalised.	Accepted
D3.1	Model constructs validation	The purpose of this report is to validate the multi-agent model of integrated model constructs. This is achieved via three steps, namely 1) analysis of the model constructs against hazards from our validation set, 2) development and execution of a formal simulation model of an existing ATM scenario, and 3) interviews with domain experts about the validity of the integrated model constructs.	Accepted
D4.1	Draft review of SESAR 2020 ConOps	The Terminal Manoeuvring Area (TMA) T1 operation, as described in the RESET project, is considered as a benchmark towards the study and analysis of SESAR 2020 concept of	Accepted

		operation. In this draft version, a description is provided of operating modes of the agents and technical systems involved in the scenario, the mechanism by which agents interact, and operating modes of the agents which may lead to unsafe or even catastrophic events.	
D4.2	Review of SESAR 2020 ConOps	The Terminal Manoeuvring Area (TMA) T1 operation, as described in the RESET project, is considered as a benchmark towards the study and analysis of SESAR 2020 concept of operation. A description is provided of operating modes of the agents and technical systems involved in the scenario, the mechanism by which agents interact, and operating modes of the agents which may lead to unsafe or even catastrophic events.	Accepted
D4.3	Initial modelling and analysis of SESAR 2020 ConOps	This report proposes a compositional hybrid systems' paradigm that appropriately models each agent acting in ATM scenarios, as well as their interaction. The notion of critical observability is used as a formal tool for analyzing Multi-Agent Situation Awareness (MASA) inconsistencies in ATM systems. Efficient algorithms are proposed towards the systematic analysis of MASA inconsistencies for ATM procedures where a large and realistic number of agents operate. Finally, the proposed framework is applied to the analysis of the Terminal Manoeuvring Area T1 operation that has been chosen in deliverable D4.2 as a meaningful case study within the SESAR 2020 ConOps.	Accepted
D4.4	Final modelling and analysis of SESAR 2020 ConOps	A compositional hybrid systems' paradigm is used to model agents interacting in ATM scenarios. The notion of critical observability is used as a formal tool for analyzing possible inconsistencies due to Multi-Agent Situation Awareness (MASA) and additional hazards. Efficient algorithms are applied for systematic analysis of MASA and hazards inconsistencies of the Terminal Manoeuvring Area T1 operation.	Accepted
D5.1	Draft assessment of MAREA approaches in safety analysis and design	This draft report discusses how the MAREA approaches can be used in safety analysis and design, and it compares them with other approaches. It is explained how the MAREA model constructs can be integrated with Multi-Agent Dynamic Risk Modelling (MA-DRM) and how this compares with the traditional safety risk assessment approaches of Probabilistic Risk Assessment (PRA) and Human Reliability Assessment (HRA). The MAREA approaches are compared with two other approaches in resilience analysis, namely the Functional Resonance Analysis Method (FRAM) and Systems-Theoretic Accident Model and Processes (STAMP)-based approaches. It is explained how the MAREA approaches can be integrated in the Concept Lifecycle Model (CLM) of the European Operational Concept Validation Methodology (E-OCVM).	Accepted
D5.2	Assessment of MAREA approaches in safety analysis and design	This report explains how the MAREA model constructs can be integrated with Multi-Agent Dynamic Risk Modelling (MA-DRM) and how this compares with traditional safety risk assessment approaches. Next, it explains how the agent-based modelling approach can be integrated in the Concept Lifecycle Model (CLM) of the European Operational Concept Validation Methodology (E-OCVM). The MAREA agent-based modelling approach is compared with two other approaches in resilience analysis, namely the Functional Resonance Analysis Method (FRAM) and Systems-Theoretic Accident Model and Processes (STAMP)-based approaches. It is concluded, that the MAREA approach provides novel methods for prospective analysis of safety implications of resilience in ATM, which are complementary to already on-going resilience engineering developments in ATM.	Accepted

D6.1	Studying hazards for resilience modelling in ATM	This report includes the paper and presentation of the WP-E project MAREA, which were presented at the First SESAR Innovation Days at Toulouse, France, from 29 November – 1 December 2011.	Accepted
D6.2	Agent-based modelling of hazards in ATM	This report includes the paper and presentation of the WP-E project MAREA, which were presented at the Second SESAR Innovation Days at Braunchweig, Germany, from 27-29 November 2012.	Accepted
D6.3	MAREA papers at the 3rd SESAR Innovation Days	This report includes the papers and presentations of the WP-E project MAREA, which are planned to be presented at the Third SESAR Innovation Days at Stockholm, Sweden, from 26 - 28 November 2013.	Planned

Table 1 - List of Project Deliverables

3 Dissemination Activities

3.1 Presentations/publications at ATM conferences/journals

First SESAR Innovation Days, 2011

A paper entitled “Studying hazards for resilience modelling in ATM” [1] was presented by Sybert Stroeve (NLR) at the First SESAR Innovation Days in Toulouse, France, 29 November – 1 December 2011. This paper describes the basis for the MAREA project development. It describes model constructs of existing safety analysis methods. It presents a broad set of ATM hazards, highlighting various sources of performance variability in the ATM socio-technical system. It discusses interviews with pilots and controllers about their ways to deal with hazards. It studies the potential of the existing model constructs to describe the performance variability indicated by the hazards. It is concluded that multi-agent dynamic risk modelling can represent a wide variety of performance variability in complex ATM scenarios and has the potential to systematically analyse risk and resilience. At the conference, several participants showed interest in the list of identified hazards.

Third Air Transport and Operations Symposium, 2012

A paper entitled “Modelling of Human Performance-Related Hazards in ATM” [2] was presented by Alexei Sharpanskykh (VU) at the ComplexWorld Event of the Air Transport and Operations Symposium in Delft, the Netherlands. In the paper it is explored to what extent agent-based model constructs are capable to model hazards that may potentially occur within air traffic operations. In the audience representatives from academia and industry were present. The presentation was accepted well. After the presentation 3 questions from the audience followed.

Second SESAR Innovation Days, 2012

A paper entitled “Agent-Based Modelling of Hazards in ATM” [3] was presented by Tibor Bosse (VU) at the Second SESAR Innovation Days in Braunschweig, Germany, 27-29 November 2012. The paper studies agent-based modelling of hazards in Air Traffic Management by adopting a previously established large database of hazards in current and future ATM as point of departure, and exploring (in three phases) to what extent agent-based model constructs are able to model these hazards. The audience consisted of around 25 people from academia as well as industry. The presentation was accepted well, and triggered 3 plenary questions from the audience, as well as a number of off-line discussions.

Tenth USA/Europe Air Traffic Management Research and Development Seminar, 2013

A paper entitled “Modelling of potential hazards in agent-based safety risk analysis” [4] was presented by Henk Blom (NLR) at the Tenth USA/Europe Air Traffic Management Research and Development Seminar in Chicago, USA, 10-13 June 2013. This paper presents 38 model constructs that are able to capture more than 97% of identified ATM related hazards in an agent-based model. The paper also shows that four of the five main model constructs are related to four widely used modelling domains in aviation, i.e. system reliability, human performance simulation, human reliability analysis, and aircraft trajectory simulation. However, the model construct that captures the highest percentage of hazards (41%) is related to the more recent domain of multi-agent systems modelling.

Third SESAR Innovation Days, 2013

A paper entitled “Safety criticality analysis of air traffic management systems: A compositional bisimulation approach” [5] has been submitted for presentation at the Third SESAR Innovation Days, Stockholm, Sweden, 26-28 November 2013. The paper presents a compositional framework to accurately describe the behaviour of the agents operating in ATM scenarios and of their interaction. It provides results that reduce the computational effort required in detecting safety critical situations. Benefits from the use of this approach are illustrated on the Terminal Manoeuvring Area T1 operation.

Third SESAR Innovation Days, 2013

A paper entitled “Agent-based modelling for analysis of resilience in ATM” [6] has been submitted for presentation at the Third SESAR Innovation Days, Stockholm, Sweden, 26-28 November 2013. This paper provides an overview of a library of model constructs for agent-based modelling in ATM and shows the integration of these model constructs. It is shown that the library of model constructs can effectively model a large set of hazards in ATM and ways are discussed towards effective use of these model constructs for the analysis of safety-focused resilience.

3.2 Presentations/publications at other conferences/journals

Hybrid Autonomous Systems Workshop, 2012

Giordano Pola (AQUI) participated as an invited speaker at the Hybrid Autonomous Systems 2012 (HAS 2012, http://personalpages.manchester.ac.uk/staff/Manuela.Bujorianu/HAS2012.htm), held in Tallinn (Estonia) on 31 March 2012. HAS 2012 is a satellite event of the European Joint Conferences on Theory & Practice of Software 2012 (ETAPS 2012, http://www.etaps.org/2012/) and focuses on the use of formal methods for the analysis of autonomous hybrid systems. In his presentation Giordano illustrated the research conducted by AQUI within the MAREA Project. The audience was interested in the results presented and asked details regarding the complexity reduction techniques employed in the analysis of TMA T1 scenario. Manuela Bujorianu, chair of HAS 2012, was interested in this research topic and in the MAREA project and is interested in a possible future research collaboration.

4th IFAC Conference on Analysis and Design of Hybrid Systems, 2012

Marika D. Di Benedetto (AQUI) participated to the 4th IFAC Conference on Analysis and Design of Hybrid Systems (ADHS-12) http://www.adhs12.org/, held in Eindhoven (The Netherlands), 6-8 June 2012. ADHS-12 is an international conference in the area of modelling, analysis and design of hybrid systems. In her presentation Marika illustrated part of the research conducted in L’Aquila within the MAREA project. She discussed complexity reduction techniques based on compositional bisimulation as a formal tool for the formal analysis of the novel SESAR 2020 concept of operation. She also discussed a preliminary example concerning the analysis of the Terminal Manoeuvring Area T1 operation. The audience was interested in the theoretical results presented and also in the application of these results to the analysis of ATM systems.

4th International Conference on Applied Human Factors and Ergonomics (AHFE)

During the 4th International Conference on Applied Human Factors and Ergonomics (AHFE), San Francisco (CA), USA, 21-25 July 2012, Sybert Stroeve presented the paper "How well are human-related hazards captured by multi-agent dynamic risk modelling?" [7]. Based on an inventory made in MAREA D1.2, the paper provides an overview of the types of model constructs (with emphasis on human models) that are used to represent hazards in aviation safety studies. The audience consisted of about 25 people from research centers and universities. The presentation was accepted well and followed by several questions from the audience.

Hybrid Autonomous Systems Workshop, 2013

Hybrid Autonomous Systems (HAS 2013) is a satellite workshop of the ETAPS 2013 (http://www.etaps.org/). HAS 2013 was held at Università La Sapienza in Rome on March 17th 2013. The workshop gathered together researchers from the community of multi-agent systems and hybrid systems and interesting contributions were presented. Giordano Pola was one of the co-chairs of the workshop. Marika Di Benedetto was invited lecturer at the workshop. Marika’s talk concerned design and implementation of large-scale complex cyber-physical systems, of which ATM systems are a key example. The audience was interested in the theoretical results presented by Marika. In particular, Marta Capiluppi, an expert on multi-agent systems from the University of Verona, expressed her interest in establishing a research collaboration with Marika’s group on multi-agent systems with application to ATM systems.

IEEE/WIC/ACM International Conference on Intelligent Agent Technology, 2013

A paper entitled "An Integrated Multi-Agent Model for Modelling Hazards within ATM" [8] was accepted for presentation at The 2013 IEEE/WIC/ACM International Conference on Intelligent Agent Technology in Atlanta, USA, 17-20 November 2013. The objective of the paper is to integrate identified agent-based model constructs into a large multi-agent model. To illustrate the integration approach, a formal description of a selected combination of model constructs is presented and the results are discussed.

52nd IEEE Conference on Decisions and Control, 2013

A paper entitled “A critical bisimulation approach to safety criticality analysis of large-scale air traffic management systems” [9] was accepted for presentation at the 52nd IEEE Conference on Decisions and Control in Florence, Italy, 10-13 December 2013. The paper introduces the notion of arena of agents as an abstract description of large-scale complex systems and in particular of ATM systems. It uses the notion of critical bisimulation as a tool for complexity reduction. The proposed framework is applied to analysis of safety criticalities of the Terminal Manoeuvring Area T1 operation.

Twelfth Conference on Practical Applications of Agents and Multi-Agent Systems, 2014

A paper entitled “Agent-Based Simulation of Aviation Incidents - Integrating Three Cognitive Agent Models” [10] is about to be submitted for presentation at the Twelfth Conference on Practical Applications of Agents and Multi-Agent Systems, Salamanca, Spain, 4-6 June 2014. In the paper, existing model constructs are used to develop a formal, executable model of an existing ATM scenario in the context of an aircraft that descends below the minimal descent altitude (MDA) because of impaired conditions of the flight crew members. Based on the model, some ‘proof-of-concept simulations’ are generated that describe (at a high level of abstraction) ways that hazards can evolve in such scenarios.

3.3 Demonstrations

No demonstrations were organized in the MAREA project.

3.4 Exploitation plans

NLR

NLR has a considerable research history in and is a main driver of developments in agent-based modelling for safety assessment of air transport operations. NLR has initiated the MAREA research to better understand the range of hazards that can be modelled by available model constructs and to extend the library of agent-based model constructs. NLR intends to apply this extended library in application cases of ATM safety and resilience analysis for its worldwide customers in the air transport sector. NLR will also use the extended library of model constructs in follow-up research on advanced agent-based models for safety and resilience analysis, e.g. in the current EC FP7 project Resilience2050.

VU University Amsterdam

VU Amsterdam has a main interest in Agent-Based Modelling and Simulation. From the perspective of this partner, the main results of the MAREA project consist of the integrated multi-agent model that was developed in WP2 and validated in WP3. More specifically, the library of model constructs developed in the project are of great value for the Agent community, since they provide a useful starting point for the development of (cognitive) agent-based models in the future. Since the model constructs have been specified at a generic level, such future use of the model constructs is not limited to applications in the Air Traffic Management domain. In this respect, the fact that part of the model constructs (and their integration) have been formalised offers an additional advantage. For example, the formal integration of the model constructs for processes like Situation Awareness, Operator Functional State, and Decision Making can be re-used in applications with various purposes (e.g., simulation, human-computer interaction, and serious gaming) and in various domains (e.g.,

incident management, social safety, and the military). Since VU is currently participating in a number of research projects in these domains, the intention is to re-use the developed model constructs in these applications.

University of L'Aquila

Formal methodologies available in the literature on analysis and control of hybrid systems were not appropriate to fully address the study of the impact of multi-agent situation-awareness inconsistencies and of hazards in ATM procedures. This has spurred AQUI researchers to explore novel research topics on the analysis and control of hybrid systems, which comprise critical observability, compositionality of hybrid systems, and algorithms for the reduction of computational complexity in the analysis of hybrid systems. AQUI believes that the mathematical formalism that was developed can be of help in assisting ATM experts in rendering the TMA T1 procedure, and possibly other novel ATM procedures under development, more robust with respect to non-nominal operating modes. Moreover, while being inspired by concrete problems in the analysis of ATM systems, the aforementioned research has been conducted at an abstract level, and as such, is promising of being applicable also to different research domains than ATM systems.

4 Total Eligible Costs

Date	Deliverables on Bill	Contribution for Effort	Contribution for Other Costs (specify)	Status
	D0.0, D0.1, D1.1, D4.1, D0.2, D1.2, D4.2	77,768.00 Euro (exc. VAT)	Travel & subsistence costs: 671.35 Euro	Paid
15-May-2012	D0.3, D0.4, D2.1, D6.1	70,503.00 Euro (exc. VAT)	Travel & subsistence costs: 686.57 Euro	Paid
29-Nov-2012	D0.5, D0.6, D2.2, D2.3, D4.3	140,404.00 Euro (exc. VAT)	Travel & subsistence costs: 2,458.55 Euro	Paid
13-Jun-2013	D0.7, D0.8, D2.4, D4.4, D6.2	94,628.00 Euro (exc. VAT)	Travel & subsistence costs: 2,363.04 Euro	Paid
Nov-2013	D0.9, D0.10, D3.1, D5.1, D5.2, D6.3	157,293.00 Euro* (exc. VAT)	Travel & subsistence costs: 11,970.49 Euro*	Planned
Grand total	-	558,746.00 Euro* (exc. VAT)	Travel & subsistence costs: 18,150.00 Euro*	-

Table 2 Overview of Billing

Company	Planned man-days	Actual man-days	Total Cost	Total Contribution	Reason for Deviation
NLR	239	239*	292,464 Euro*	219,348 Euro*	-
VU	241	241*	179,228 Euro*	179,228 Euro*	-
AQUI	342	342*	177,968 Euro*	160,170 Euro*	-
Grand total	822	822*	649,659 Euro*	558,746 Euro*	-

Table 3 Overview of Effort and Costs per project participant

*Estimate (Bill 5 has not yet been completed)

5 Project Lessons Learnt

What worked well?
The opportunity to conduct interviews with pilots and air traffic controllers turned out to be an excellent way to bridge the gap between the research and the application domain. The support of SJU/Eurocontrol in the organization of the interviews has been appreciated a lot.
The MAREA project involved a consortium of three partners with a mix of expertise: agent-based modelling for ATM risk assessment (NLR), general agent-based modelling (VU) and arenas of hybrid systems (AQUI). This allowed the partners to learn in-depth relevant models and methods.
The qualitative argumentation approach for the analysis of model constructs, hazard modelling and model integration made it possible to analyse a large set of model constructs and hazards, without losing effort and time on case specific details that would be required in quantitative instantiations.
Collaboration with the parallel ComplexWorld PhD project of [redacted] resulted in fruitful cross-fertilisation.
Our project officer considerably supported the effectiveness and efficiency of our research by good reviews, short communication lines, an open view for cross-connections with other projects, and a flexible attitude towards project changes.
The close locations of NLR and VU supported the frequent conduct of face-to-face meetings.
The strong collaboration of AQUI researchers with NLR researchers was very important and fruitful, in particular for deeply understanding key mechanisms of ATM operations in SESAR ConOps.
What should be improved?
Although both NLR and VU are working in the area of Agent-Based Modelling, the difference in background caused some confusion in the beginning of the project. For future collaboration, it would be helpful to have a common definition of concepts like model, simulation, qualitative, and so on.
Hazard modelling was analysed by mental simulation. In future research, it would be useful to analyse hazard modelling by more in-depth approaches.
A mathematical model was proposed that accurately describes the TMA T1 operation in both nominal and non-nominal operation modes. However, a number of simplifying assumptions has been made on the operation. In future work it is planned to eliminate the simplifying assumptions in order to render the proposed methodology applicable to realistic scenarios of the TMA T1 operation, and more generally to other novel ATM procedures.

Table 4 - Project Lessons Learnt

6 References

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