EXPLORATORY RESEARCH

D3.5 Opportunities for innovative ATM research (interim report)

Deliverable 3.5

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Engage

THE SESAR KNOWLEDGE TRANSFER NETWORK

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Abstract

This document reports on the topics and academic disciplines of past Exploratory Research projects, notably SESAR Workpackage E (long-term and innovative research) and SESAR Exploratory Research (ER) with a view of tracing the evolution of research as well as opportunities for future research. This analysis is complemented with relevant activities in Engage, such as the Engage thematic challenges.

Table of Contents

List of tables

List of figures

Executive summary

Engage is the SESAR 2020 Knowledge Transfer Network (KTN). It is managed by a consortium of academia and industry to promote and facilitate the development of air traffic management research in Europe. Its focus is two-fold: inspiring new researchers and helping to align exploratory and industrial research, through a wide range of activities and financial support actions.

This document provides a review of previous SESAR Exploratory Research, not so much in order to synthesise their results and achievements (such an analysis is provided elsewhere) but with a view to obtaining a more global perspective of the subject matter and academic disciplines explored in these projects. A total of 40 SESAR WP-E projects and 35 SESAR ER projects from the ER1 and ER3 waves have been reviewed in such a fashion. The analysis is complemented with relevant findings from the WP-E *HALA! – Towards Higher Automation Levels in ATM* – and *ComplexWorld* networks and the *Engage* Knowledge Transfer Network.

1 Introduction

1.1 The Engage KTN

Engage is the SESAR 2020 Knowledge Transfer Network (KTN). It is managed by a consortium of academia and industry, with the support of the SESAR Joint Undertaking, to promote and facilitate the development of air traffic management research in Europe. Its focus is two-fold: inspiring new researchers and helping to align exploratory and industrial research, through a wide range of activities and financial support actions.

1.2 Objectives of this document

This document provides a systematic review of the scope and outcomes of previous European innovative/exploratory ATM research projects in order to illustrate progress made, changing objectives and avenues that could be explored further.

1.3 Scope of D3.5

The analysis provided in this document is based on a review of the following sources:

- SESAR WP-E (long-term and innovative research) projects following the first and second call;
- The SESAR WP-E HALA! – Towards Higher Automation Levels in ATM – and ComplexWorld networks;
- SESAR 2020 Exploratory Research projects following the ER1 and ER3 calls (call ER2 exclusively funded RPAS projects which were found less relevant for D3.5);
- The SESAR Knowledge Transfer Network, Engage, notably the Engage thematic challenges and the outcomes of the workshops held in Q4/2018.

2 Analysis of SESAR Exploratory Research

2.1 Thematic Areas in SESAR WP-E and ER

A series of Exploratory Research calls have been let by SESAR. Within SESAR 1, Workpackage E (long-term and innovative research) let two calls (2010 and 2012) resulting in two networks and a total of 40 research projects. Within SESAR 2020, Exploratory Research calls ER1 (2015) and ER3 (2017) led to a total of 35 projects and the Engage Knowledge Transfer Network. For all four calls, thematic areas were defined to focus the limited resources on areas which were expected to lead to greatest benefits. The thematic areas evolved slightly over time and are shown below; colours indicate related areas.

Table 1. SESAR Exploratory Research call thematic areas

WP-E First Call	WP-E Second Call	ER-1 Call	ER-3 Call
			Knowledge Transfer Network
Toward Higher Levels of Automation in ATM	Toward Higher Levels of Automation in ATM	Automation, Robotics and Autonomy	
			Separation Management
		Advanced Air Traffic Services	Trajectory Based Operations
Mastering Complex Systems Safely	Mastering Complex Systems Safely	Complexity, Data Science and Information Management	
	Information Management, Uncertainty And Optimisation		
Legal Aspects Of Paradigm Shift (Economics And Performance)	Enabling Change In ATM	Economics, Legal and Regulation	
		Environment and meteorology in ATM	

WP-E First Call	WP-E Second Call	ER-1 Call	ER-3 Call
		Enabling Aviation Infrastructure	CNS for General Aviation
			CNS
	System Architecture and System Design	ATM Operations, Architecture, Performance and Validation	ATM Architecture, performance and validation
		High Performing Airport Operations	

Projects and networks covering the different thematic areas are shown below.

Table 2. SESAR Exploratory Research projects and networks

WP-E First Call	WP-E Second Call	ER-1 Call	ER-3 Call
			Knowledge Transfer Network
Toward Higher Levels of Automation in ATM HALA! Network STREAM SUPEROPT C-SHARE ZeFMaP ADAHR MUFASA UTOPIA TESA SPAD	Toward Higher Levels of Automation in ATM HALA! Network AGATHA SAFECORAM NINA MOTA 6th Sense ERAINT ProGA ACF	Automation, Robotics and Autonomy TaCo MINIMA AGENT STRESS AUTOPACE	
			Separation Management
		Advanced Air Traffic Services R-WAKE SALSA COPTRA OptiFrame PARTAKE	Trajectory Based Operations ADAPT COTTON

WP-E First Call	WP-E Second Call	ER-1 Call	ER-3 Call
Mastering Complex Systems Safely ComplexWorld Network MAREA NEWO ONBOARD COMPASS ASHiCS CASSIOPEIA POEM ELSA	Mastering Complex Systems Safely ComplexWorld Network TREE ComplexityCosts EMERGIA	Complexity, Data Science and Information Management BigData4ATM DART MALORCA BEST	
	Information Management, Uncertainty And Optimisation RobustATM SecureDataCloud IMET		
Legal Aspects Of Paradigm Shift ALIAS	Enabling Change In ATM ACCESS SATURN ALIAS II ACCHANGE AEROGAME	Economics, Legal and Regulation COCTA COMPAIR Vista	
(Economics And Performance)			
		Environment and meteorology in ATM TBO-MET PNOWWA ATM4E	
		Enabling Aviation Infrastructure SAPIENT NAVISAS	CNS for General Aviation EMPHASIS
			CNS ENVISION GATEMAN

WP-E First Call	WP-E Second Call	ER-1 Call	ER-3 Call
	System Architecture and System Design FLITE SCALES EMFASE	ATM Operations, Architecture, Performance and Validation APACHE INTUIT AURORA PACAS	ATM Architecture, performance and validation Domino EvoATM
		High Performing Airport Operations RETINA MOTO	

Although the maximum funding of projects in WP-E and ER1 and ER3 was slightly different (the maximum SESAR contribution was €600k in WP-E; €600k for ER1/ER3 Excellent Science and Outreach projects and €1M for ER1/ER3 Application-Oriented projects) the number of projects can be used as a rough indication of weight the different thematic areas had in WP-E and ER. Note that a better balance between these areas might have been desirable and the greater number of projects in certain areas is indicative of the greater number of (good) project proposals received.

Figure 1 shows the number of projects awarded in the different areas in WP-E and ER calls.

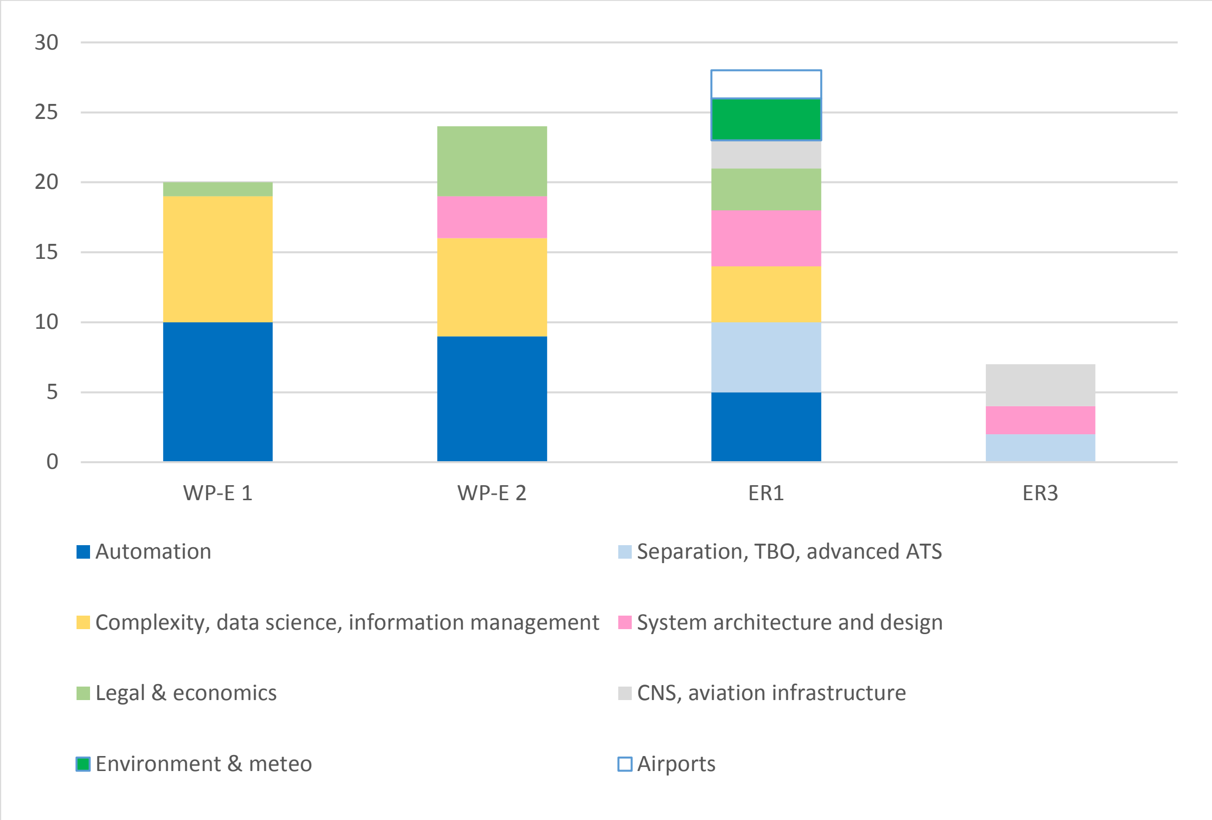

Figure 1. Number of Exploratory Research projects per thematic area

3 ATM Scope, Scientific Disciplines and Validation Approach in SESAR WP-E and ER

The SESAR Exploratory Research projects in the first and second WP-E calls, and SESAR 2020 ER1 and ER3 were analysed with regard to the ATM Scope, the academic discipline and the validation technique used by the projects. 73 projects were analysed (for two of the 75 projects documentation was not easily available in the required detail). General findings are reported here; a more detailed analysis can be found in Appendices A, B and C.

Despite the relatively large sample, there are a few methodological limitations:

- The review was carried out based on the publishable summary of the projects and are hence somewhat dependent on the project teams' views of their approach and achievements.
- The categories used to classify ATM Scope, academic discipline and validation technique evolved slightly during the analysis; revisiting the analysis might lead to slightly altered results and this could be considered for future editions of this document.
- The analysis reported here was carried out by experts external to the projects with general knowledge of ATM and scientific methods but not necessarily specific expertise on the validation techniques, academic disciplines or ATM operations explored in any specific project.
- The seven ER3 projects in this analysis have started but have not yet finished. This means that results are not fully available and the analysis had to refer to the projects' plans and ambitions rather than achievements.

The 73 projects studied covered four calls in the period from 2010 to the present day. Analysing the categories of each call separately and comparing them to trace an evolution might be an interesting endeavour. We still refrained from presenting such an analysis for a number of reasons:

- The projects awarded in each of the calls are a function of the scope of the call. For example, the scope of ER1 included excellent science (TRL0) and application-oriented (TRL1) research projects whilst ER3 only called for application-oriented proposals.
- Upon closure of each of the calls, a greater number of proposals were received in the more 'traditional' scope areas (such as automation) than in less common areas (such as legal and economics). As part of the selection process, the best proposals according to the selection criteria defined in the call were selected. This led to the situation that the number of proposals per topic was not necessarily balanced.
- Again, the ER3 projects are ongoing so that an analysis is very preliminary.

3.1 ATM scope

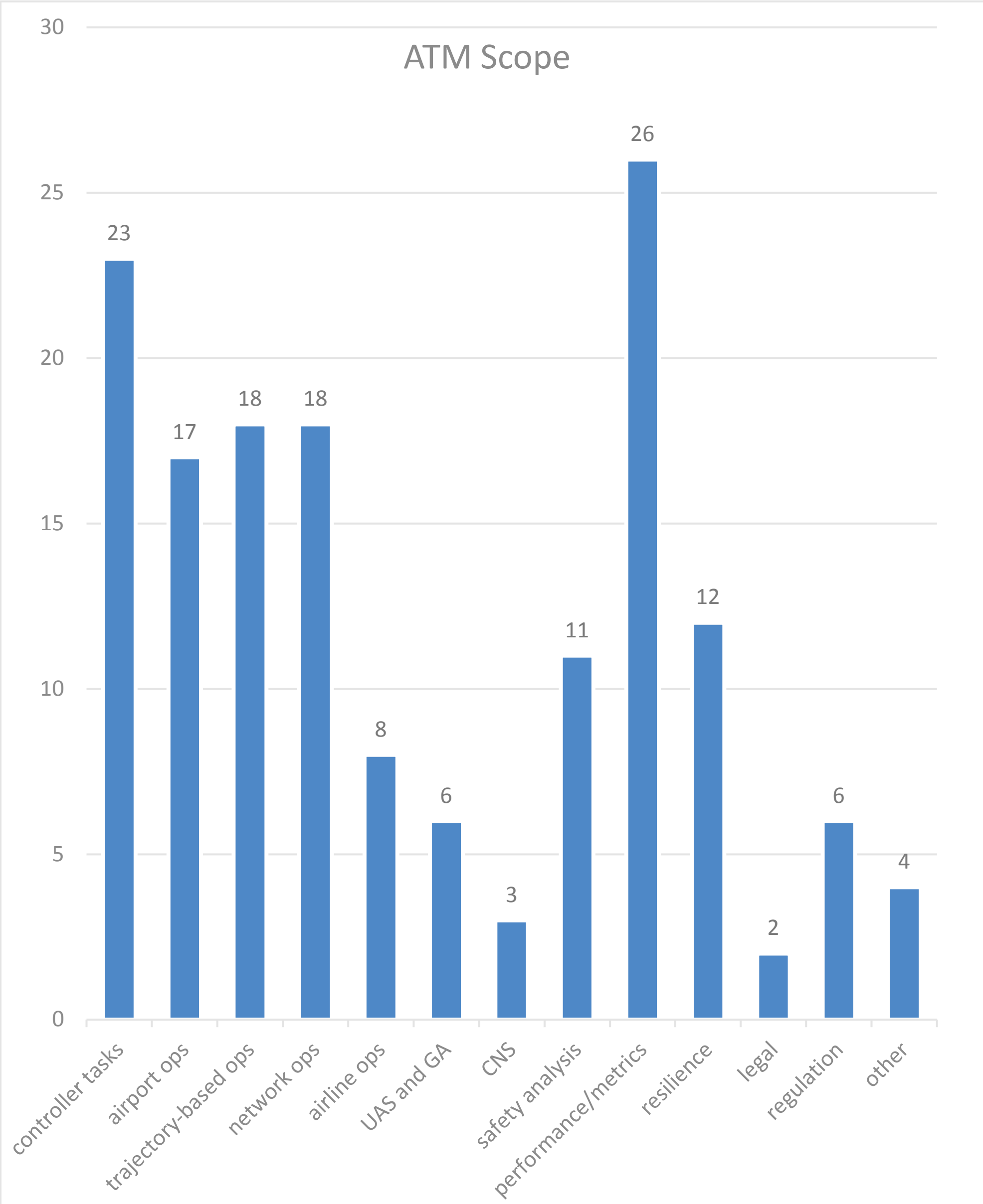

Figure 2. ATM Scope of WP-E and ER projects

Figure 2 shows the ATM Scope of WP-E and ER projects. Note that many projects were related to more than one of the categories defined for scope so that the sum of the individual categories is greater than 73, the number of projects reviewed. Note that the projects awarded following ER call 2 (UAV) were not included in the analysis – including the ER2 projects would have led to a different distribution of ATM Scope.

When reviewing the ATM Scope the following observations were made:

- ANSPs and the NM were the target stakeholders, with 48 projects looking at aspects of their work. 23 projects involved tasks performed by controllers, while 17 examined network operations, and 18 concerned trajectory-based operations.
- Airport operations were the subject of 17 projects while airline operations were involved in just eight of them.
- Only six projects had a relation to smaller aircraft and only four of those looked at the looming problem of integrating UAS into the airspace. The SESAR JU is managing other, less innovatory projects in this domain, however.
- The performance of the ATM system was either studied by, or could be improved by the results of, 26 projects.
- Eleven projects had a regard to the safety aspects of ATM, a fairly low number for a topic that is generally considered 'paramount'. Twelve were concerned with the resilience of the system.
- The legal and regulatory side of ATM was examined by 8 projects, with one of these looking also at legal/liability concerns.
- CNS was the topic of three projects, while three others touched on change management, economics, investment decisions and security.

3.2 Scientific disciplines

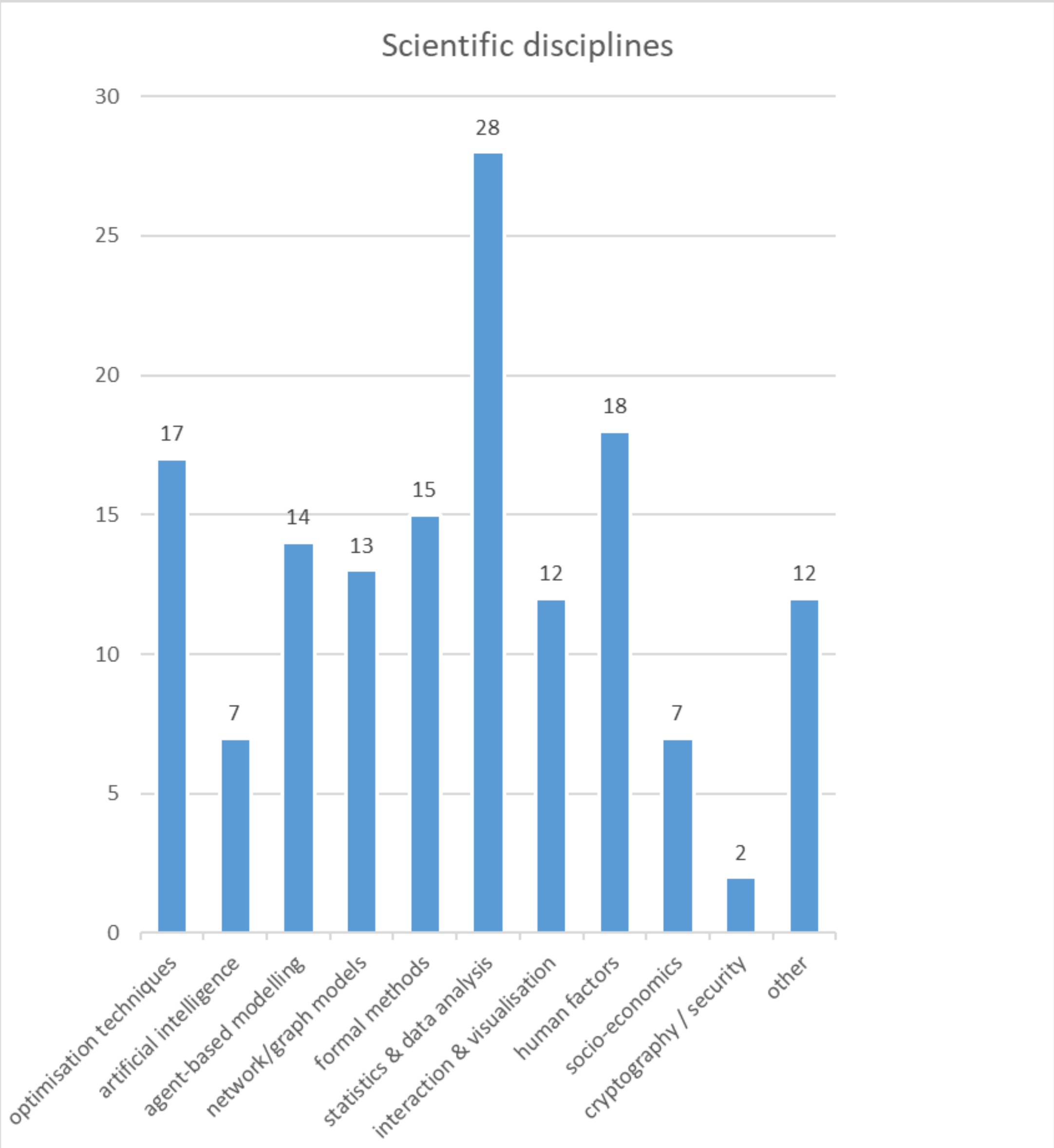

Figure 3. Scientific disciplines of WP-E and ER projects

Figure 3 shows the scientific disciplines of the investigated projects – note again that many projects were related to more than one category. The following observations were made:

- 17 projects used established optimisation techniques, with another seven using novel techniques of artificial intelligence (essentially machine learning and occasionally evolutionary computation).

- The use of agent-based models is now established, having been used in 14 projects.
- The use of formal methods and semi-formal models such as networks and graph models is also widespread with 25 projects using one or other of these techniques and three using both.
- 28 projects explore or rely mainly on statistical methods and data analysis techniques. However, the number of projects performing statistical analysis as a method is, as expected, much the higher of the two.
- A total of 18 projects explore examine the area of human factors which therefore seems a well-covered area.
- 13 projects are concerned with interaction and visualisation techniques. The true number of projects actually exploring these techniques is lower because these 12 projects include many that only use these techniques as a tool rather than a field of study.
- A small number of projects focus on socio-economics (7), cryptography and security (2), regulation and liability (2) and meteorology (2).

3.3 Validation approach

Figure 4 shows the validation approach followed by WP-E and ER projects. As before, the total number is greater than the number of projects since a combination of validation techniques was often used. The following observations were made:

- Three projects (4%) had no visible means of validation available. Of these "Emphasis" had very little information publicly available and "ACChange" made no reference to validation in its publishable summary.
- 59 projects used at least one of the following approaches for validation: experimental tools (simulators etc.) (42); experiments (30); or data and measurements (27) to validate their outcomes.
- 26 projects defined their validation as using the airspace, some defined which airspace they used; 34 defined operator roles which were evaluated during the validation.
- Uncertainties were a part of the validation of twelve projects, whereas eight of them used other techniques.

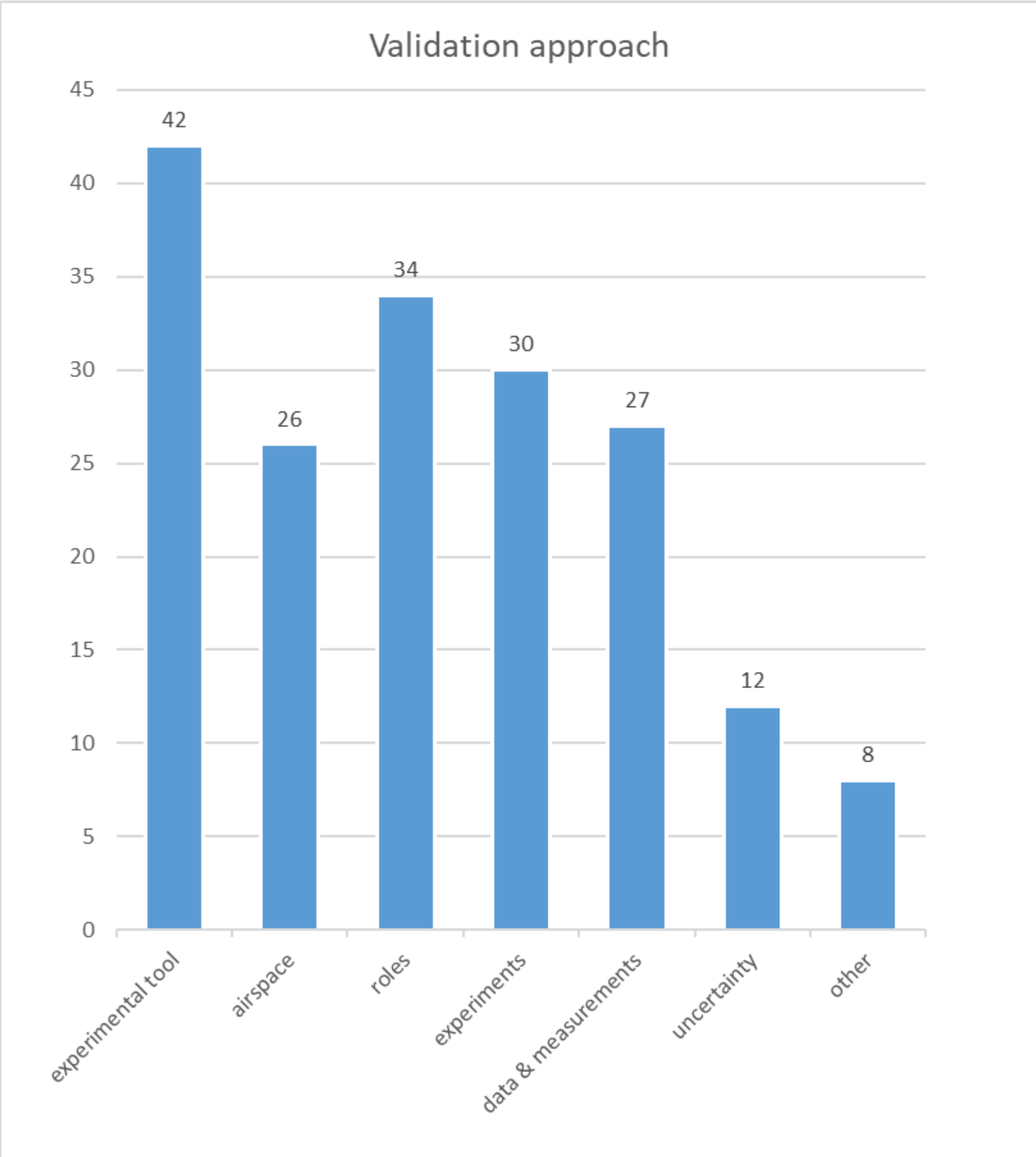

Figure 4. Validation approach of WP-E and ER projects

3.4 Conclusions

The analysis presented here is preliminary in nature and could be repeated or confirmed in future editions of this document, for example using a consistent set of categories and integrating the results of ER3 projects and future ER calls. However, despite some limitations in the approach a number of interesting conclusions can be drawn.

Very few projects actually 'fail' in the sense that they come to the conclusion that the concepts and ideas proposed when starting the project just do not work. This is surprising especially for

Exploratory Research where both costs and success rates (measured by the number of studies leading to implementation) are significantly lower than for example in industrial research or implementation. Not surprisingly, management theory on innovation suggests that the further concepts and ideas are from implementation (in the sense of concept or product maturity) the smaller the percentage that actually make all the way to implementation.

A number of observations come to mind:

- If most projects really do succeed in the sense that they deliver a concept or prototype that are implemented in downstream research then perhaps the calls have not been ambitious enough in the sense that they encourage exploring new and uncharted territory. Our very subjective and preliminary impression is that this has not been the case, since many projects did actually explore new areas.
- Demonstrating that a concept of approach does not work is, from a scientific point of view, just as satisfying as demonstrating that it does work yet very few projects, if any, document such conclusions. It might be that our research culture does not reward proven negative findings sufficiently. Publishing 'negative' findings should be encouraged, for example specifically encouraging scientific publications.
- In the absence of well-formulated hypotheses and a well-defined scientific method to confirm or refute their hypotheses the project team will gravitate towards calling their project a success rather than a failure. It is our impression that this explanation holds true not for the majority but at least for a fraction of the projects analysed. Failure to apply a correct scientific method must be discouraged. For example, the soundness of the scientific approach and the existence of a clear research/experimental/validation plan should be established as a criterion in the proposal selection and contract negotiation phase.
- Perhaps as a relatively small community, we shy away from making harsh judgements on our peers' results.
- The 'broken innovation pipeline' is often cited, meaning that the transfer and uptake of ideas and concepts that are successful on a lower TRLs to applied research could be improved. Involvement of players from more mature phases of R&D in exploratory research must be encouraged further and the SJU and Engage are putting in place a number of measures to do so.

Elaborating further on the last bullet point and recognising that several projects within WP-E have led to interesting results: it is somewhat sobering to realise that not all of these were followed up as much as could have been possible. Problems that could potentially offer part of an explanation are:

- A process for following up on interesting findings, e.g. by granting an extension to successful research projects was, at least at the time of the projects reported here, not in place or very *ad hoc*. Note that delay in following up on interesting findings often means that know-how is lost as researchers have moved on to other fields.
- Perhaps not enough emphasis has been put on documenting and disseminating research results and, again, perhaps the processes for this were not well in place. We acknowledge that a period of six months after project closure is eligible for disseminating project results in the ER4 call; this was not the case for WP-E, ER1 and ER3.
- Perhaps the proposal selection process is not sufficiently punitive of research that repeats well-established existing work.

- The approach, culture and composition of project teams are quite different for exploratory and industrial research so that extending ER projects into industrial research is not a solution. A real transfer of the results is needed and this requires better exchange between earlier and later phases of the research cycle. Note that this transfer is bidirectional to ensure that (a) operational problems and constraints are sufficiently well understood by ER projects and (b) industrial research guides and 'owns' the potential of ER projects.
- Growing a community around successful concepts and projects might help counter attrition of expertise and exploiting their potential better. This is what the WP-E networks and the Engage thematic challenges attempt(ed) to do.
- The use of standard datasets, scenarios and validation approaches would increase the comparability and reproducibility of research results and hence benefit transfer.

We recognise that these problems are increasingly being addressed in the present (ER1, ER3) and future (ER4) set-up of Exploratory Research; for instance, 11 ER1 projects were identified as inputs for Wave 2 IR solutions, and many fundamental research projects were assessed to be mature enough to move to the applied research, and would have a chance of being selected for continuation.

4 Challenges identified by WP-E Scientific Networks

4.1 ComplexWorld: Complexity Challenges in ATM

The ComplexWorld Network, funded through SESAR WP-E (long-term and innovative research) between 2010 and 2016 identified the following challenges for future ATM research [7]:

<u>A. Developing and demonstrating new metrics in ATM:</u> New metrics should extend the range of flight-centric metrics (e.g. average departure delay) currently used by industry, and cover such performance aspects as cost, resilience, and passenger service delivery. The use of non-classical metrics (including complexity) is expected to continue to play an important role in many instances, although not necessarily required in all cases. Consideration of the complex sociotechnical nature of the air transportation system remains underexploited. Improved pathways towards industry adoption of appropriate new metrics are also important.

<u>B. Building resilience into systems design taking into account emergent behaviour:</u> A key challenge is how to make the ATM system more resilient regarding disturbances and disruptions. This resilience performance question is, however, only one side of the ATM performance medal; the other side consists of established key performance areas such as economy, capacity and safety. Therefore, we are in need of an ATM system design that is more resilient against disturbances and disruptions and at the same time maintains a good balance with other key performance areas. In support of a step change in future ATM design, this challenge concerns building resilience into systems design taking into account emergent behaviour.

<u>C. Understanding trade-offs through metrics:</u> Current (Key) Performance Indicators and the trade-offs between them are not sufficiently understood, especially in terms of stakeholder impacts, such as costs. Some established work has been carried out by EUROCONTROL on the trade-offs between en-route capacity provision and ATFM delay, but this represents one of few such examples. Trade-offs between monetised and non-monetised metrics are particularly challenging.

<u>D. Data science and managing and visualising (big) data:</u> Data science techniques together with complex systems theory and practice open a new approach in the study of the complexity of air transport. Significant research challenges in this field are data management, data processing, data sharing and protection, deep analytics or visualisation. For aviation to access and manage the datasets generated by the different agents, suitable data infrastructure paradigms need to be developed. Extracting knowledge from data that represent, predict and improve the behaviour of the system, requires collecting, validating, formatting, correcting and consolidating different datasets. Considering the heterogeneity of the data sources (aircraft, airlines, passengers, navigation services,

ground handling, retail sub-systems...) the management of big data can be considered a complex challenge in the aviation field. Even more, if we consider the volume, variety and velocity of the datasets. Other techniques barely explored in aviation, like data protection paradigms or data visualisation can be enormously helpful in the field of air transport, ensuring the analysis of the performance, the use of existing resources and the support to the decision-making processes can be improved several orders of magnitude.

<u>E. Integrating multi-agent systems into decision-support tools:</u> Multi Agent Systems (MAS) in Air Traffic Management (ATM) can have important advantages for policy makers as they allow evaluation during the design of a novel operation and they allow performing scenario simulations in terms of what-if studies through tuning the relevant parameters of the model. Moreover, MAS and Agent-Based Models (ABM) can be relevant for the investigation of the behaviour of the ATM main actors, as they can provide useful insights about the learning mechanisms on which the agents' behaviour is based. These features can be fruitfully exploited by using integrated decision-support tools (DST), based on MAS and ABM that will help in selecting the best policies and strategies to improve the general efficiency of the ATM system, building on the analysis of historical data.

<u>F. Integrating uncertainty into decision-support tools:</u> There are many scenarios in ATM where uncertainty plays an important role. Examples of these include scheduling of arrivals/departures, routing around adverse weather, trajectory prediction, conflict resolution, and flow management. In the past, most integrated decision-support tools (DST) that have been developed to help manage these scenarios commonly neglect uncertainty. However, including the effect of uncertainty in DSTs might help to improve their efficiency, thus benefiting the ATM system. There are many challenges in including uncertainty in a DST: for instance, it is not clear what type of statistical models should be used to realistically capture uncertainty; there is also a trade-off between robustness and performance: if one tries to accommodate too high levels of uncertainty, it might lead to excessive conservativeness in DST solutions. In addition, while in a deterministic setting an optimal solution is easy to define, this notion is not totally clear in an uncertain environment.

<u>G. Characterisation of meteorological uncertainty:</u> Optimum routes for air traffic have a strong dependency on meteorological parameters such as the position of the jet stream or the strength and/or direction of prevailing winds. Moreover, in a very few cases and limited areas, MET hazards can potentially perturb the nominal traffic (significant weather conditions); indeed, adverse weather continues to be a major cause of delays in air travel. However, accurate numerical weather prediction (NWP) forecast models continue to be challenging due to issues including uncertainty in observations used to initialise the forecasts and an incomplete understanding of the physical processes that occur in the atmosphere.

<u>H. Model-based identification of emergent behaviours at the design stage, including comparison with reality:</u> In support of a step change in future ATM design, this challenge concerns model-based identification of emergent behaviours from early design stage on, including comparison with reality. Established system design takes a conservative approach regarding emergent behaviour by trying to avoid it. However, this may be counterproductive because for a complex socio-technical system, it is impossible to identify and learn understanding emergent behaviour at all frequencies without conducting adequate simulations. As long as not all emergent behaviour is identified and understood it is unknown which are positive and which are negative. Though once understood, there is the possibility to adopt or strengthen positive emergent behaviour and to avoid or mitigate negative emergent behaviour. This means there is great design value in timely identifying positive and

negative emergent behaviours of future socio-technical designs at frequencies ranging from regular to extremely rare.

4.2 HALA! Automation Challenges

The SESAR WP-E research network HALA! – Towards Higher Automation Levels in ATM has reviewed challenges pertaining to ATM automation in their position paper [8, 9]. HALA! considers the need to align the research efforts into two challenging broad areas of special interest, from the research point of view, as crucial and complementary issues.

- aircraft trajectory hierarchal, spatial, and temporal cohesion among the different ATM organisations and agents, considered as part of a sociotechnical multi-agent system, as key elements for an efficient integrated ATM; and
- trajectory management, including trajectory optimisation, DCB, TS safety barriers, detect and avoid systems, autonomy of flight/vs, centralised services provision, latency effects on all kind of agents remotely controlled are, among others, key research issues, that involves especially remotely piloted aircraft systems (RPASs).

HALA! proposes to evolve toward higher level of automation ATM by providing decision tools delivering compatible and efficient trajectories for all airspace users, enhancing the hierarchical, spatial, and temporal cohesion among the different organisations/agents involved in the planning and operational phases of the trajectory management process. To this end, automation shall also provide decision tools within the trajectory management process itself focused on trajectory optimisation, traffic synchronisation, safety nets behaviour, and compatibility between autonomy of flights and centralised services provision.

Associated to the two HALA! general ATM oriented challenges presented previously, there are related scientific challenges dealing with specific issues associated to automation processes:

1. resilience and system degradation;
2. ability to formalise, understand, and model the system to be controlled in all possible normal and abnormal operational conditions, and to face possible unexpected situations;
3. the adequateness and correctness of the human role in the control system, in particular the ability to ensure human motivation, trust, and dependence on automation, and the ability to maintain situational awareness;
4. responsive and adaptive automation able to adapt the level of automation and allocation of functions to agents and performed by humans or machines depending on needs; and
5. change management when going towards higher levels of automation and introducing new technologies.

5 Engage Thematic Challenges

In order to facilitate the orientation of exploratory ATM research towards operational challenges the Engage network has let a call for thematic challenges. These challenges, once established, should provide a means for research and industry together, to develop and propose approaches to address the underlying problems. Funding available in a subsequent catalyst call should help address some of these. The selection process as well as the conclusions of a first series of workshops are documented in greater detail in Engage deliverables D3.4 (Thematic challenges priming report for first workshops) [3] and D2.5 (Annual combined thematic workshops progress report) [4] and will therefore only briefly be summarised here.

5.1 Establishing thematic challenges

Following the call, 54 proposals were received from 33 organisations, covering industry (including airspace users and ANSPs), research institutes, universities and consultancies. All 54 proposals were evaluated individually by eight members of the Engage Awards Board based on the following criteria:

- Operational relevance
- Focus of challenge
- Capability of network and/or proposer

As expected, there were several links between the 54 proposals; grouping these and ranking them in the order of the evaluations the related proposals received led to a prioritised list of themes. In this fashion, six themes were identified, from which the top four were selected; two remaining themes are maintained as candidate future themes. The four themes cover ten out of the top twelve individual proposals. The four selected themes have been established as the Engage thematic challenges; they are:

- Vulnerabilities and global security of the CNS/ATM system;
- Data-driven trajectory prediction;
- Efficient provision and use of meteorological information in ATM;
- Novel and more effective allocation markets in ATM.

The experts submitting the two to four top-scoring proposals leading to each of these challenges were invited to form a challenges team which was accompanied by one or two Engage members and invited to organise a thematic challenge workshop. Workshops were held in October and November 2018 for three out of the four challenges (Vulnerabilities and global security of the CNS/ATM system will hold a workshop in Q1/2019).

5.2 Engage TC Workshop recommendations

The three thematic challenge workshops involved a series of technical presentations and a subsequent facilitated session in which workshop participants brainstormed on:

- What specific types of follow-up research are likely to be useful to mature the state of the art (especially those that could be addressed by catalyst funding from the Engage KTN)?
- What are the measures of success that could be used to assess the progress of the challenge?
- What are the likely barriers to prevent progress towards maturing the challenge, and how might we overcome them?

The conclusions of the three workshops which took place in Q4/2018 are replicated here for completeness (a fuller description can be found in Engage deliverable D2.5 (Annual combined thematic workshops progress report) [4].

TC2: Data-driven trajectory prediction

The following have been identified as *example* ideas for potential further exploration:

1. Trajectory predictors supporting airborne self-separation: definition of requirements and concept development of enabling technologies;
2. Improved DCB: enhanced TPs integrating uncertainty assessment, robust planning and cost-efficiency assessment at network level;
3. Data-driven approaches for understanding and prediction of AU preferences and behaviours enabling improved NM operations;
4. Mapping requirements definition and concept development of data-driven TP in support of collaborative multi-sector CD&R;
5. Optimising and integrating local planning activities with a view to assess, contain and communicate their network effects;
6. Improving data-sharing and data access to satisfy AU, NM and ANSP technical and organisational requirements and expectations.

TC3: Efficient provision and use of meteorological information in ATM

The following have been identified as *example* ideas for potential further exploration:

1. Very high-resolution, very short-range forecasts using numerical weather prediction models and observational data assimilation;

2. Quantifying the sensitivity of operational processes to MET uncertainty, comparing these with other sources of uncertainty;
3. Incorporation of ensemble weather information into decision-support tools, adapted for different ATM stakeholders;
4. Accurate prediction of weather conditions (e.g. visibility, glide-path wind) influencing airport arrival and departure operations;
5. Consolidation of climate risk assessment methodologies for airports;
6. Creating a climate forecast 'baseline' for aviation from the IPCC UN panel report.

TC4: Novel and more effective allocation markets in ATM

The following have been identified as *example* ideas for potential further exploration:

1. Incorporating behavioural science methods into improved traffic demand and distribution predictor tools for ANSPs and UDPP;
2. Assessing if incentives or penalties work as better drivers of behaviour: whether social norms can be used to improve collaboration;
3. Predicting and avoiding undesirable behaviour, such as gaming, in ATM allocation mechanisms;
4. Building a better understanding of 'equity' and 'fairness', plus trade-offs across different stakeholders, and with 'flexibility';
5. Improving the assessment of uncertainty and disturbance, and of new mechanism implications for policy recommendations;
6. Running models and tools in shadow-mode, with practical user interfaces and value in output metrics (e.g. costs, overloads).

6 Conclusions

The analysis presented here is based on SESAR WP-E and ER project calls as well the HALA!, ComplexWorld and Engage networks. Despite its preliminary nature and its limitation, some interesting findings can be derived (and should perhaps be confirmed with a greater scope and more established methodology in future revisions of this document).

6.1 Lessons learned

1. **Build the community.**

   SESAR Exploratory Research started with WP-E projects and networks in which areas such as automation, human factors and human-computer interaction were covered. From the beginning, attempts were made to include non-traditional areas and these attempts seem gradually have to come to fruition. For reasons explained in Section 3 we refrain from analysing the evolution of topic areas over time. Yet even without such an analysis one can observe that some areas such as complexity and data science, economics and legal aspects are now an integral part of Exploratory Research. Some observations:

   a) Projects in new areas have often been most successful when they involved experts from new fields, often naïve to ATM who teamed up with the experts from the ATM research community.

   b) The research community in new areas has to be built and strengthened over time and this cannot be achieved quickly. Conference attendance, invitations to workshops and project bids are stepping stones for involving players from new areas.

2. **Transfer results of successful research projects.**

   The degree to which interesting results from Exploratory Research projects are picked up by subsequent projects and lead into higher maturity phases could certainly be improved. A number of avenues could be explored:

   a) Establish a process for slightly extending *successful* projects, for example, with a view to solving specific challenges identified in the project, exploring the potential of specific approaches and disseminating the results.

   b) Improve the transfer of knowledge, data and concepts between exploratory and industrial research in both directions, predominantly through involvement of industrial research members in Exploratory Research. Although we acknowledge that some progress has been made, this is still an area for improvement.

c) Establish a proposal selection process that is less forgiving of projects reproducing established findings (whilst encouraging the maturing of successful concepts to downstream research/higher TRLs).

3. Encourage reporting on unsuccessful concepts

Although we would expect the majority of Exploratory Research projects to conclude and demonstrate that the concepts or methods explored are not successful, very few projects actually document such 'negative' results. Such documented failure, unless due to flaws in the scientific methods, would be desirable and should be encouraged, for example by:

a) Instilling a culture that rewards documenting negative as well as positive research results (a section could be added to the project report template that explicitly solicits findings about approaches that do not work).

b) Not shying away from calling a failure by its name. Although the merit of a research project is difficult to establish, a somewhat subjective and very sensitive review of past projects shows some patterns. How these can be used to reward researchers with a good track record in the proposal selection process could be discussed.

4. Insist on the use of established scientific methods.

Not all projects reviewed in this document applied a sound scientific method leading to unclear, anecdotal or debatable results. Whilst we recognise that not all projects lend themselves to quantitative and statistical analyses, the use of a sound method leading to statistically significant results should be encouraged as far as possible.

5. Improve availability and use of standard scenarios and datasets.

Encourage the use of standard tools, datasets, scenarios, etc. to improve comparability and transferability of research results and thus benefit uptake through downstream research phases. Make such datasets and scenarios available to the community, solving problems of ownership and confidentiality.

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8 Acronyms

ABM	Agent-Based Models
AI	Artificial intelligence
ANSP	Air Navigation Service Provider
ATFM	Air Traffic Flow Management
ATM	Air traffic management
ATS	Air Traffic Services
AU	Airspace user
CD&R	Conflict detection and resolution
CNS	Communication, navigation, surveillance
CSA	Coordination and Support Action
DCB	Demand-capacity balancing
DST	Decision-support tools
EC	European Commission
ER	Exploratory Research
H2020	Horizon 2020 research programme
HALA!	Higher Automation Levels in ATM (WP-E Network)
IPCC	Intergovernmental Panel on Climate Change
KTN	Knowledge Transfer Network
MAS	Multi Agent Systems
MET	Meteorology/meteorological services
NM	Network Manager
NWP	Numerical weather prediction
PMP	Project management plan
RPAS	Remotely piloted aircraft systems
SESAR	Single European Sky ATM research
SIDs	SESAR Innovation Days
SJU	SESAR Joint Undertaking

TBO	Trajectory-based operations
TC	Thematic challenge
TP	Trajectory predictor/prediction
TRL	Technology Readiness Level
UAS	Unmanned aircraft system
UAV	Unmanned aerial vehicle
UDPP	User-Driven Prioritisation Process
UN	United Nations
WP	Workpackage
WP-E	SESAR Workpackage E (long-term and innovative research)

Appendix A: Project Review – ATM Scope

Project	SUPEROPT	NEWO	STREAM	ONBOARD	ASHICS	POEM	TESA	MUFASA
controller tasks	conflict resolution strategies		conflict detection and resolution				risk-based conflict resolution	conflict resolution strategies
airport ops		departures prioritisation						
trajectory-based ops			exploiting shared business trajectories				trajectory prediction	
network ops				ATM system predictability				
airline ops								
UAS and GA								
CNS								
safety analysis					automated hazard analysis			
Performance /metrics		delay propagation		ATM performance; delay; knock-on effects		flight-centred; passenger-centred		individual performance variability
resilience				weather				
legal								
regulation								
other								

Project	ADAHR	MAREA	C-SHARE	COMPASS	ALIAS	CASSIOPEIA	UTOPIA	ZEFMAP
controller tasks				resolution incl. knock-on effects				tower workflow: electronic flight strips; hand-over points
airport ops	airport operation centre automation					night curfew		integrated arrival management and taxiing
trajectory-based ops			shared representation; route advisories				trajectory synchronisation; required time of arrival; aircraft intent	
network ops	airspace organisation and management; automation					en-route slot swaps		
airline ops						dynamic cost indexing		
UAS and GA								
CNS								
safety analysis		exploiting hazard database		safety patterns				failure mode analysis
Performance /metrics								
resilience		human flexibility and monitoring						
legal				liability	Automation in socio-technical systems - legal aspects			
regulation				national;				

				supra-national				
other								

Project	**SPAD**	**ELSA**	**ROBUSTATM**	**AGATHA**	**SAFECORAM**	**NINA**	**ALIAS2**	**MOTA**
controller tasks	AMAN	conflict resolution strategies; ATCo workload			sharing of authority between automation and humans	sharing of tasks between automation and humans	sharing of liability between automation and humans	
airport ops			Runway utilisation and planning stability					automated taxiing
trajectory-based ops				seamless integration				
network ops		Predictability of last-filed flight plan; sector capacity mgt	pre-tactical planning					
airline ops								
UAS and GA	RPAS with self-separation			GA				
CNS								
safety analysis		correlation between STCAs; critical navpoints						
Performance /metrics	productivity	satisfaction			delay; fuel burn; pollution; airport capacity; airline capacity			environmental impact
resilience	degradation propagation				resilience engineering			
legal								
regulation								
other								

Project	6SENSE	FLITE	SCLOUD	TREE	ACCESS	SCALES	ACCHANGE	EMFASE
controller tasks	ground control							
airport ops		runway capacity; satellite airports; intermodality	slot trading		slot allocation			
trajectory-based ops		separation in TMA						
network ops								
airline ops				slot swapping; cancellation				
UAS and GA								
CNS								
safety analysis						early warning		
Performance /metrics			delay	reactionary delays				
resilience	resilience			bad weather		resilience abilities		
legal								
regulation					slot regulation			
other							(No validation activity discussed)	security

Founding Members

EUROPEAN UNION EUROCONTROL

Project	SATURN	ERAINT	COMPLEXITYCOSTS	PROGA	AEROGAME	EMERGIA	AGENT	AUTOPACE
controller tasks			increased sector ops			fully automated tactical control	separation management; collision avoidance	greater automation and performance
airport ops			advanced CDM					
trajectory-based ops		flight intent		flight intent	Transition to 4D trajectory-based ATM	conflict-free; strategic and tactical	Trajectory options for collision avoidance	
network ops								
airline ops			dynamic cost indexing; passenger re-accommodation				cooperative collision avoidance	
UAS and GA		RPAS integration					RPAS/UAS integration	
CNS								
safety analysis				safety assessment			maintained levels of safety	preliminary safety assessment
Performance /metrics			cost of delay; flight-centred; passenger-centred					
resilience			local disturbances; network-wide disturbances					
legal								
regulation	charging mechanisms							
other					investment decisions			

Project	MINIMA	TACO	STRESS	BIGDATA4ATM	DART	MALORCA	BEST	ATM4E
controller tasks	greater automation and out-of-the-loop phenomena; vigilance	human-automation handover	Controller vigilance; Human-in-the-loop; ATC automation			CPDLC		
airport ops		Surface movement optimisation; control of automation						
trajectory-based ops					trajectory prediction			
network ops				passenger behaviour	DCB		SWIM applications	traffic flows
airline ops								flight planning
UAS and GA								
CNS								
safety analysis								
Performance /metrics	preliminary safety assessment			delay				environmental impact
resilience		non-nominal conditions						
legal								
regulation								
other								

Project	PNOWWA	TBO-MET	COCTA	COMPAIR	VISTA	MOTO	RETINA	COPTRA
controller tasks								
airport ops	ground operations			Competition in Airport services		remote tower	tower in low visibility	
trajectory-based ops		trajectory planning						probabilistic prediction
network ops			DCB	Competition in ATM services	ATM cost efficiency			DCB
airline ops								
UAS and GA								
CNS								
safety analysis								
Performance /metrics	delay		flexibility	efficiency	Trade-offs between KPAs; Departure delay; Cost efficiency			predictability
resilience	adverse weather							
legal								
regulation			route charges; market competition	route charges; market competition	market competition			
other								

Project	OPTIFRAME	PARTAKE	R-WAKE	SALSA	NAVISAS	SAPIENT	APACHE	AURORA	INTUIT
controller tasks		departure clearances	wake vortex separation	CPDLC					
airport ops									
trajectory-based ops	pre-tactical	interdependencies					trajectory planning		
network ops		DCB; capacity management; decision support					dynamic airspace configuration; free routes; DCB		
airline ops							cruise climb		
UAS and GA					small aircraft	BVLOS UAS			
CNS				ADS-B for non-radar airspace	satellite navigation	CNS; Air-ground datalink			
safety analysis			separation schemes				airspace complexity		
Performance /metrics	predictability; flexibility	Airspace optimisation					trajectory optimisation	flight efficiency	Trade-offs between KPAs
resilience						datalink resilience			
legal									
regulation									
other									

Project	PACAS	DOMINO	EMPHASIS	COTTON	GATEMAN	ADAPT	ENVISION	EvoATM
controller tasks								
airport ops		E-AMAN					Surface surveillance	
trajectory-based ops				effectiveness of capacity management processes in TBOs				
network ops		UDPP		Dynamic airspace configuration; capacity management		traffic prediction; flight information sharing & flexibility to mitigate network congestion		
airline ops		Dynamic cost indexing	GA/Rotorcraft and UAS integration					
UAS and GA								
CNS								
safety analysis								
Performance /metrics		impact of applying new mechanisms; coupling of systems						performance-ATM design relationship
resilience					managing threats to GNSS			
legal								
regulation								
other	change management							

Project	**ACF**	**IMET**
controller tasks		
airport ops	RWY and TXY ops, de-icing, terminal security	
trajectory-based ops		probabilistic prediction
network ops		
airline ops		Flight planning
UAS and GA		
CNS		
safety analysis		
Performance /metrics	Capacity forecasting	fuel burn and flight duration
resilience	Disrupted operations	
legal		
regulation		
other		

Appendix B: Project Review – Scientific Disciplines

Project	SUPEROPT	NEWO	STREAM	ONBOARD	ASHICS	POEM	TESA	MUFASA
optimisation techniques & control systems	mixed-integer linear programming; global, non-linear		linear time algorithm?	integer programming; disturbance feedback	random-hill climbing			
artificial intelligence					evolutionary computation; search harness			
agent-based modelling								
network/graph models		mesoscopic model; dynamic graphs		aggregate flow model		factor analysis for data reduction; granger causality for time series		
formal methods								
statistics & data analysis						factor analysis for data reduction; granger causality for time series	trajectory prediction from data analysis	
interaction & visualisation	constraint visualisation							
human factors								automation acceptance and bias

Project	SUPEROPT	NEWO	STREAM	ONBOARD	ASHICS	POEM	TESA	MUFASA
socio-economics								
cryptography / security								
other								

Project	ADAHR	MAREA	C-SHARE	COMPASS	ALIAS	CASSIOPEIA	UTOPIA
optimisation techniques & control systems							
artificial intelligence							
agent-based modelling		ABM; multi-agent dynamic risk modelling				ABM modelling architecture	
network/graph models							
formal methods		critical observability + compositional bisimulation; hybrid system modelling	functional model		flow diagrams; risk trees		language for trajectory modelling
statistics & data analysis				time-based pattern detection; synchronisation likelihood		game theory	
interaction & visualisation							
human factors	automation acceptance; trust; situational awareness; workload	reuse of cognitive modelling constructs	joint cognitive system design		fair treatment of operators		
socio-economics							
cryptography / security							
other					argument-based case structure; doctrinal analysis		

Project	ZEFMAP	SPAD	ELSA	ROBUSTATM	AGATHA	SAFECORAM	NINA
optimisation techniques & control systems				robust optimisation; stochastic optimisation/ mixed-integer linear programming		graph-based optimisation	adaptive automation
artificial intelligence							
agent-based modelling			multi-layered: tactical and strategic				
network/graph models		graph-based route network					
formal methods	workflow process modelling; failure mode, effects and criticality method (FMECA)	multi-viewpoint models: FRAM; HAMSTERS				functional models; flow diagram	state-classifier algorithm
statistics & data analysis			community detection				
interaction & visualisation	performance visualisation						
human factors	operator productivity					task allocation	assessing cognitive state; skill/rule framework
socio-economics							
cryptography / security							
other					(wireless CNS technologies)		

Project	ALIAS2	MOTA	6SENSE	FLITE	SCLOUD	TREE	ACCESS	SCALES
optimisation techniques & control systems		graph-based optimisation						
artificial intelligence			machine learning; pattern recognition					
agent-based modelling		multi-agent models				Datatree-driven ABM	Agent-based modelling	
network/graph models								semantic wiki
formal methods	workflow models							multi-viewpoint enterprise architecture; EATMA
statistics & data analysis		learning effects	outlier detection	Unspecified “analysis” of future scenarios	data confidentiality and sensitivity; benchmarking	Datatrees	asymmetry of information	
interaction & visualisation		ground-control interface	eye tracking; voice recognition; gesture control; time-series visualisation					
human factors	user-centred design	trust in automation	human error; stress					
socio-economics					sealed-bid auctions; elections		combinatorial auctions; bounded rationality	
cryptography / security					secure multi-party computation			
other	liability							

Project	ACCHANGE	EMFASE	SATURN	ERAINT	COMPLEXITYCOSTS	PROGA	AEROGAME
optimisation techniques & control systems			stackelberg games				
artificial intelligence							
agent-based modelling	network congestion game						serious games
network/graph models	economic network model				stochastic layered network model	barriers and precursors diagram	
formal methods		EOCVM				functional hazard analysis	
statistics & data analysis	asymmetry of information			Analysis by human-in-the-loop simulation		statistical characterisation of nominal behaviour	
interaction & visualisation		textual and visual risk assessment methods				cockpit displays	board game; electronic score board
human factors		cognitive fit theory; actual vs perceived effectiveness				situational awareness	learning effect
socio-economics	incentives; price-caps; vertical integration; fore-runners for tech-nology adoption; labour union model; public utility model		pricing mechanisms		early adopters and followers		last-mover advantage
cryptography / security		threat catalogues					
other	economic regulation	method evaluation method					

Project	EMERGIA	AGENT	AUTOPACE	MINIMA	TACO	STRESS	BIGDATA4ATM	DART	MALORCA
optimisation techniques & control systems					gaming				
artificial intelligence								reinforcement learning	machine learning
agent-based modelling	agent-based safety assessment	intelligent agents						ABM	
network/graph models	petri models								
formal methods									
statistics & data analysis							data mining	Data-driven trajectory prediction	
interaction & visualisation									speech recognition
human factors			cognitive model; out-of-the-loop; automation acceptance and bias; training	out-of-the-loop; dynamic vigilance; attention		controller cognitive state			
socio-economics									
cryptography / security									
other									

Project	BEST	ATM4E	PNOWWA	TBO-MET	COCTA	COMPAIR	VISTA	MOTO	RETINA
optimisation techniques & control systems				stochastic optimisation					
artificial intelligence									
agent-based modelling									
network/graph models				probabalistic trajectory prediction		economic network model			
formal methods	semantic technologies								
statistics & data analysis			nowcasting	nowcasting	trade-off analysis		trade-off analysis		
interaction & visualisation								virtual reality; head-mounted display; tactile stimulus; auditory stimulus	augmented reality; see-through head-mounted display; conformal head-up displays
human factors								situational awareness; workload	
socio-economics						market-based design; unbundling			
cryptography / security									
other		climate chemistry modelling	meteorology	meteorology			model development		

Project	COPTRA	OPTIFRAME	PARTAKE	R-WAKE	SALSA	NAVISAS	SAPIENT	APACHE	AURORA
optimisation techniques & control systems	model-driven state estimation	multi-objective optimisation	constraint logic programming		system-of-systems			pareto front	
artificial intelligence									
agent-based modelling									
network/graph models			petri nets					multi-scale models	
formal methods				dynamic risk model; conditioned individual risk					
statistics & data analysis		trade-off analysis	Spatio-temporal interdependency analysis						Data analytics
interaction & visualisation									
human factors									
socio-economics									
cryptography / security									
other						(technology evaluation)	System architecture development		

Project	INTUIT	PACAS	DOMINO	EMPHASIS	COTTON	GATEMAN	ADAPT	ENVISION	EvoATM
optimisation techniques & control systems									
artificial intelligence	machine learning							Machine learning	evolutionary computing
agent-based modelling		serious games	ABM						ABM
network/graph models							Percolation		
formal methods					Baysian network modelling				
statistics & data analysis	data-driven modelling techniques		complex network science		Complexity science; Uncertainty		Percolation		sensitivity analysis
interaction & visualisation	visual analysis; interactive dashboard							video analytics	
human factors									
socio-economics									
cryptography / security									
other				(No information found)		GNSS interference mitigation barrier development			

Project	ACF	IMET
optimisation techniques & control systems		
artificial intelligence		
agent-based modelling		
network/graph models		
formal methods		
statistics & data analysis	Probability trees	Ensemble methods
interaction & visualisation	dashboard	GUI
human factors		
socio-economics		
cryptography / security		
other		

Appendix C: Project Review – Validation Approach

Project	SUPEROPT	NEWO	STREAM	ONBOARD	ASHICS	POEM	TESA	MUFASA
experimental tool	demonstrator; what-if scenarios		numerical simulator	multi-agent simulator	numerical ATC simulator	numerical simulator		mock-up?
airspace	multi-sector Wales and NW England	at specific airports at specific times	from pre-departure to execution			n/a	all	en-route sector?
roles	en-route controller	departure mgr		network manager; airline ops mgr	en-route controller	passenger journeys		en-route controller?
experiments		numerical experiments		incl. knock-on reactionary delays		re-accommodation rules; trade-offs		varying traffic complexity, level of automation, level of conformance
data & measurements		low equipage rates				50 largest airports in Europe; busy day in September		

Project	SUPEROPT	NEWO	STREAM	ONBOARD	ASHICS	POEM	TESA	MUFASA
uncertainty		thru noise	perturbations in along track error; perturbations in estimated time of departure error	due to weather; due to unscheduled demand			along-track and cross-track wind estimates; initial mass	
other								

Project	ADAHR	MAREA	C-SHARE	COMPASS	ALIAS	CASSIOPEIA	UTOPIA	ZEFMAP	SPAD
experimental tool	serious gaming mock-up and platform	monte-carlo petri-net simulator	human-in-the-loop simulator with different levels of automation	numerical simulator	case template	multi-agent simulator	demon-strator	human-in-the-loop simulator	demon-strator
airspace	planning phase	all		en-route sectors		n/a	major hub; TMA	airports	en-route sectors (generic, 3)
roles	airport agent; airline ops mgr; network mgr; local traffic mgr; A-CDM mgr	controller		en-route controller				tower controller	en-route controller; remote pilot
experiments	5 experts; 60 students; 2 iterations	thought experiments with experts; one numerical scenario	expert workshop (7p); expert workshop (16p); 8 scenarios (3p); 1 scenario (12p)		expert workshops	baseline current ops with current traffic; scenario current ops with future traffic; scenario future ops with future traffic		5 experts	few experts
data & measurements		half hazard set reserved for validation		historical data for 44 days			heterogen-eous traffic	Hamburg airport	
uncertainty							due to wind prediction; due to bad weather cells		
other									

Project	ELSA	ROBUSTATM	AGATHA	SAFECORAM	NINA	ALIAS2	MOTA
experimental tool	numerical simulator for tactical and strategic layers	monte-carlo simulator		agent-based simulator at mesoscale	human-in-the-loop simulator; controlled experiments		human-in-the-loop simulator
airspace	en-route sectors	runway movements					ground movements
roles	en-route controller; network manager; airline ops manager	Pre-tactical and tactical slot allocation	private pilots; professional pilots; controllers		controllers; controller students	end-users and stakeholders; ACAS and RPAS experts	controllers; autonomous tugs; aircraft; taxiways
experiments	expert workshops		expert panels; mental exercises; interviews	expert workshops	expert observations; questionnaires and interviews with 37 subjects	interviews	3 iterations; 18 experts; 35 mins scenarios
data & measurements	?	200 flights at large German airport		2050 and beyond	system logs; neuro-physiologic indicators		CDG airport; different equipage ratios; different traffic density
uncertainty	perturbations of different size	gamma distribution for departure and arrival delay					non-nominal events
other						training development; achieved V3	

Project	6SENSE	FLITE	SCLOUD	TREE	ACCESS	SCALES	ACCHANGE	EMFASE
experimental tool	human-in-the-loop simulator	numerical simulator	cloud prototype	numerical simulator; what-if scenarios	agent-based simulator	demonstrator		human-in-the-loop experiments; controlled experiments
airspace	terminal area?	terminal area			network			
roles				aircraft; passengers; crews	slot coordinator; airlines; airports; passengers	experts for 4 cases		ATM experts; security experts; students
experiments	few experts; 8 * 60 mins; observations; auto-reporting (stress)				2 stakeholder workshops; 100p	interviews and observations		demographic questionnaires; focus groups; 7 iterations
data & measurements	Hamburg airport; physiological measurements	traffic up to 2050	synthetic data	1d delay data; 140d traffic data				
uncertainty	noise in sensors			stochastic connection probability				
other		achieved TRL4				achieved TRL2	(No validation information available)	training

Project	SATURN	ERAINT	COMPLEXITY-COSTS	PROGA	AEROGAME	EMERGIA	AGENT	AUTOPACE
experimental tool	numerical simulation	numerical simulations	numerical simulations	demonstrator; human-in-the-loop simulations	human-in-the-loop experiments	numerical simulations	open demonstrator	
airspace	network	en-route; terminal area	network			en-route	U-space	
roles	regulators; airports; airlines; ANSPs	controllers	ANSPs; passengers; airline ops mgr; airport ops mgr	pilots	several			
experiments	stakeholder WS; 100p	100 runs with 8 subjects		expert WS	4 experts; 3 iterations; questionnaires; observations; group discussion			preliminary hazard assessment; qualitative performance assessment
data & measurements	1 busy nominal day	extended BADA for RPAS	1 busy nominal day	from France and Netherlands				
uncertainty			local or network-wide disturbances					
other							RPAS	training

Project	MINIMA	TACO	STRESS	BIGDATA4ATM	DART	MALORCA	BEST	ATM4E	PNOWWA
experimental tool			human-in-the-loop simulator			human-in-the-loop simulator		numerical simulator	
airspace						Vienna and Prague			
roles	15 controllers; tool testing	ATCo feedback	ATCos			ATCos			airport feedback
experiments			vigilance, attention, workload, stress and type of cognitive control during execution of operational tasks						
data & measurements	neuro-physiological indictors		neuro-physiological indictors	Comparison with official statistics; case studies	Comparison with other predictions and real data				
uncertainty									
other		gaming; up to TRL1					Prototyping		

Project	TBO-MET	COCTA	COMPAIR	VISTA	MOTO	RETINA	COPTRA	OPTIFRAME
experimental tool	human-in-the-loop simulator					human-in-the-loop simulator		
airspace			regional airports in Sweden, UK, Spain and Germany					
roles		Expert (NM) evaluation				airport controller	Judgemental techniques using Barcelona ACC	
experiments				use cases				
data & measurements					impact of these stimuli, in terms of workload, performance, sense of presence and situational awareness			trade-off analysis
uncertainty								
other								

Project	**PARTAKE**	**R-WAKE**	**SALSA**	**NAVISAS**	**SAPIENT**	**APACHE**	**AURORA**	**INTUIT**	**PACAS**
experimental tool		human-in-the-loop simulator	human-in-the-loop simulator		Simulation				
airspace	London TMA data								
roles									
experiments		safety & robustness analysis							testing with SESAR solutions
data & measurements						case studies	“validated by airlines”	use cases	
uncertainty									
other				(No operational validation performed)					

Project	DOMINO	EMPHASIS	COTTON	GATEMAN	ADAPT	ENVISION	EvoATM
experimental tool							
airspace					network-wide tactical assessment	two demonstration airports	
roles					flight-centred tactical assessment		
experiments	investigative and adaptive case studies			Physical testing			
data & measurements							known scenarios and quantitative indicators
uncertainty			uncertainty characterisation				
other		(No information available)					

Project	ACF	IMET
experimental tool	mock-up	exploiting numerical weather prediction forecasts
airspace		
roles	airport actors	flight planning
experiments	2 expert WSs	
data & measurements	AMS airport, 2y	large sample of meteo measurements 36h before take-off
uncertainty	Meteo; capacity distributions	ensemble forecasts
other		

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