EXPLORATORY RESEARCH

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D1.2 Final Project Results Report

Deliverable ID:	**1.2**
Dissemination Level:	**PU**
Project Acronym:	**Engage**
Grant:	**783287**
Call:	**H2020-SESAR-2016-2**
Topic:	**SESAR-ER3-01-2016 Knowledge Transfer Network**
Consortium Coordinator:	**University of Westminster**
Edition date:	**07 October 2022**
Edition:	**01.01.00**
Template Edition:	**02.00.04**

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N/A		

Document History

Edition	Date	Status	Name / Beneficiary	Justification
01.00.00	30 August 2022	Release	Engage Consortium	New document for review by the S3JU
01.01.00	07 October 2022	Release	Engage Consortium	Incorporating S3JU comments

Engage

THE SESAR KNOWLEDGE TRANSFER NETWORK

This document is part of a project that has received funding from the SESAR 3 Joint Undertaking under grant agreement No 783287 under European Union's Horizon 2020 research and innovation programme.

Abstract

This deliverable summarises the activities and results of Engage, the SESAR 2020 Knowledge Transfer Network (KTN). The KTN initiated and supported multiple activities for SESAR and the European air traffic management (ATM) community, including PhDs, focused catalyst fund projects, thematic workshops, summer schools and the launch of a wiki as the one-stop, go-to source for ATM research and knowledge in Europe. Key throughout was the integration of exploratory and industrial research, thus expediting the innovation pipeline and bringing researchers together. These activities laid valuable foundations for the SESAR Digital Academy.

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1 Executive Summary

The Engage network ran for 4½ years, initiating and supporting multiple activities for SESAR and the European ATM community. Around two-thirds of the financing was invested back into the community, for example through catalyst fund (CF) projects and PhDs. Several firsts in European ATM were achieved.

Key throughout was integrating exploratory and industrial research (ER and IR), thus expediting the innovation pipeline and bringing researchers together. Permeating all features of the network was the pronounced and active engagement of industry. Additional, in-kind support from approximately 60 industry partners, from across the sector, and beyond Europe, ranged from PhD proposal assessment, catalyst fund support and reviewing SESAR Innovation Days papers, through to participation in summer schools.

At the core of the network were four thematic challenges (TC), supported by 14 dedicated workshops with ER and IR researchers, in addition to further specialist/technical workshops. Catalyst funding, linked to these challenges, supported 18 projects, stimulating the transfer of exploratory research results towards ATM application-oriented research, returning very high value for money. Engage here worked with 31 unique institutions, and these projects produced approximately 130 research outputs.

Ten PhDs were supported through financing and co-mentoring, working with 21 unique institutions, producing over 100 research outputs. Further support was financed by the KTN for these PhDs through travel bursaries, publication grants and funded training course places. Central to the educational and training provision of Engage were three summer schools (one physical, two virtual). The pedagogical approach evolved across the series of summer schools, from teaching the PhD candidates the fundamentals of ATM and wider research practice in 2019 (these materials forming the basis of the lecture courses published in the EngageWiki), to tailored industry presentations and methodological tutorials (2020), through to extended panel discussions with domain experts from industry, in 2021, also exploring how the PhDs could be taken forward in operational settings. Almost 100 participants, from 20 countries, participated in the 2021 summer school. These activities have laid valuable foundations for the SESAR Digital Academy.

The Engage website [59] was launched in the first month of the network, gaining almost 52k page views over the lifetime of the KTN. This was later joined by the Engage ‘knowledge hub’, known as the ‘EngageWiki’, designed as the one-stop, go-to source for ATM research and knowledge in Europe [60]. The wiki has produced a considerable number of European firsts: an interactive research map of ATM (integrating ER and IR projects); a consolidated and searchable research repository; an interactive roadmap of (future) ATM concepts; a database of over 110 undergraduate and postgraduate teaching programmes, and; supporting European ATM education and training through, *inter alia*, three introductory courses (introduction to air traffic management; airline planning and operations; airport planning and operations). The research repository describes over 350 projects, with more than 1400 deliverables/reports and over 650 conference papers. In addition, the wiki hosts various discussion fora, and advertises (free of charge) jobs, internships and PhD opportunities. User accounts are free and the wiki hosts briefing videos to explain key features to new users.

The KTN also supported the four SESAR Innovation Days during its lifetime. The consortium members closely collaborated with the S3JU, co-hosted thematic challenge workshops, presented at and

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supported various sessions, and republished the SIDs conference papers (2011-2020) in the EngageWiki.

Notable among the 58 deliverables, were D3.9 (The Engage wiki - an update on the KTN's knowledge hub functionality, research maps and repository) and D3.10 (Research and innovation insights) which are viewed as legacy deliverables from the KTN. The former (D3.9) is a reference document for the Engage wiki, detailing the data sources and repository functionality such as the clustering analysis. The latter (D3.10) highlights future research opportunities for ATM, with the basic framework structured around three research pillars. SESAR's Strategic Research and Innovation Agenda was used as a focal point of comparison and detailed proposals for future research, plus research enablers and platforms, have been suggested for SESAR 3.

2 Project Overview

2.1 Operational/Technical Context

Previous attempts to involve industry in the earlier maturity phases of ATM research, have only partly been successful. The Engage consortium recognised that just inviting representatives from industry to participate in exploratory research network events, for example, has not sufficed in the past and that additional actions and incentives were necessary. Permeating all features of the proposed network was the pronounced and active engagement of industry partners, hence the name: 'Engage'. This stressed at every point the engagement of industry, from the enhanced SIDs, through the PhDs, and on to new mechanisms for industry to build better links between ER and applied research.

2.2 Project Scope and Objectives

Engage set out to assess, foster, store, transfer, communicate and share the SESAR exploratory research results among (and outside) the whole ATM and aviation community, with a special focus on ensuring a strong link with the industry and SESAR industrial research.

More specifically, the objectives of Engage were to:

- Manage the SESAR Knowledge Transfer Network towards a scientific, technical and dissemination success all while maintaining the highest level of quality within guidelines approved by the European Commission and the S3JU.
- Manage the network's communication related activities, including on-line (e.g. website and social media) and organising workshops whilst supporting S3JU initiatives such as the organisation of the SIDs and coordination with the SESAR Scientific Committee.
- Build an inspiring and user-friendly ATM observatory (EngageWiki) to monitor, identify and analyse relevant new opportunities for innovative ATM research, with a repository to host tools, reports and publications and a roadmap of innovative and interdisciplinary ATM concepts beyond SESAR 2020.
- Stimulate the transfer of exploratory research results towards ATM application-oriented research by identifying the maturity of research results and facilitating the link with higher-maturity research.
- Support European ATM education and training in the ATM community to develop new talent with a deep knowledge of the future ATM scientific research needs; to sustain a supply of ATM research talent and to stimulate the next generation of ATM operational and engineering staff.

2.3 Work Performed

Since the launch of the KTN in 2018 in support of the S3JU, Engage has sought to inspire and encourage new researchers whilst also helping to align SESAR exploratory and industrial research, through a wide range of activities and financial support actions. More recently Engage has been supporting the vision

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of the **SESAR Digital Academy** (SDA), such as through the EngageWiki [60] and the education/training material and other resources it hosts (illustrated in Figure 1 and reported in D3.9[1]), in particular:

- Teaching resources, consisting of **three complete lecture programmes**:
  (i) introduction to air traffic management
  (ii) airline planning and operations
  (iii) airport planning and operations
  These were prepared by the consortium and are available to any research institution wishing to use them, free of charge. The courses are also reported separately in D5.15.
- A database of **over 100 European university undergraduate and postgraduate programmes** offering ATM, air transport and related topics (compiled by the consortium and open to registered users to contribute).
- A listing of **internship positions and funded PhD opportunities** (compiled by the consortium and open to registered users to contribute).

Additionally, the SESAR Scientific Committee's investigations into the SDA were supported by Engage, such as through the dedicated 'Shaping a future European ATM Academy' session at the 3rd summer school – part of a programme designed with a strong focus on the Engage PhDs' technical results. PhDs and summer schools were part of the extensive platform that Engage has built for the SDA, in coordination and consultation with the S3JU.

Figure 1: EngageWiki education and training links

To stimulate the next generation of interdisciplinary ATM researchers, **Engage funded a PhD programme**. The Engage Call for PhDs and post-graduate theses was open between August and November 2018, with proposals evaluated by the Engage Awards Board. Ten of the PhDs awarded funding went on to launch in 2019, each assigned with a mentor from within the consortium. PhD candidates and supervisors have actively participated in the TC workshop programme, SESAR Innovation Days and summer schools as well as other events relevant to their topics. PhD outputs include a wealth of presentations and articles (see Section 2.4) and their final reporting has been published on the Engage website (PhD abstracts and final reports page) and as D5.18-D5.27. At the point of Engage closure, nine of the candidates were in the final stages of their studies, with formal PhD completion following shortly after in most cases. The final abstracts are available in Appendix B,

[1] Engage deliverables are listed in Table 15 and Section 5.1.

whilst the published PhD theses can be accessed from the hosting institutions (see final reporting or D5.18-D5.27 for links). Nine out of ten PhD completions is a very good conversion rate.

The **Engage summer schools** had the purpose of providing high quality education and training in the field of ATM, gathering together PhD students, experienced researchers and industry representatives. A series of three annual summer schools were organised 2019-2021, focused on Engage PhDs, but open to other postgraduate students, researchers and industry.

In 2019 (the only physical summer school, hosted by the University of Belgrade – Faculty of Transport and Traffic), the focus was on teaching the PhD candidates some of the fundamentals of ATM and wider research practice (see Figure 2 for the programme). This was highly valued by the students, many of whom had no background in ATM, and these materials now form the basis of the three lecture courses published in the EngageWiki for the benefit of future students, and as a contribution to the SDA. The summer school was attended by 30 participants, with students able to apply to Engage for financial support to assist with their travel and accommodation expenses.

Monday, 9 Sep	Tuesday, 10 Sep	Wednesday, 11 Sep	Thursday, 12 Sep	Friday, 13 Sep Room 214	Friday, 13 Sep Room 217
12.30-14.00 **Registration*** and **Lunch**** *Radosav Jovanović*	09.30-10.00 **PhD5: ML applications to extend AGENT's conflict resolution capabilities** *Ralvi Isufaj*	09.00-10.30 **Experimental methods – part 1** *Dirk Schaefer*	09.00-10.30 **Essential data sources in aviation and ATM** *Graham Tanner*	09.00-10.00 **Convective weather decision support tools – part 1** *Tatjana Bolić*	09.00-10.00 **Future concepts in ATM** *Luis Delgado*
14.00-14.15 **Welcome** *Radosav Jovanović* **The Engage KTN** *Andrew Cook*	10.00-10.30 **PhD6: Integrating weather prediction models into ATM planning** *Anastasia Lemetti*	11.00-12.30 **Experimental methods – part 2** *Dirk Schaefer*	11.00-12.30 **Performance measurement in ATM** *Andrew Cook*	10.30-11.00 **Convective weather decision support tools – part 2** *Tatjana Bolić*	10.30-11.30 **Flight planning and messaging** *Graham Tanner*
				11.00-12.30 **Making best use of airport airside capacity** *Bojana Mirković*	11.30-12.30 **Aircraft surveillance data** *Junzi Sun*
14.15-14.45 **PhD1: Decision support system for airline operation control hub centre** *Jonas Langner*	11.00-11.30 **PhD7: Advanced statistical signal processing for next generation trajectory prediction** *Homeyra Khaledian*	13.30-15.00 **The principles of ATFM** *Luis Delgado*	13.30-14.15 **SESAR ER Case study 2: ADAPT** *Tatjana Bolić*	12.30-12.45 **Closing** (Room 214) *Radosav Jovanović and Andrew Cook*	
14.45-15.15 **PhD2: Trajectory planning for conflict-free trajectories: a multi agent reinforcement learning approach** *Alevizos Bastas*	11.30-12.00 **PhD8: A pilot/dispatcher support tool based on enhanced provision of thunderstorm forecasts considering its inherent uncertainty** *Eduardo Andres Enderiz*	15.30-16.15 **Modelling methods in aviation: comparative benefits** *Gerald Gurtner*	14.15-15.15 **Delays in European aviation: trends and costs** *Andrew Cook*	12.45-14.00 **Lunch**	
15.45-16.15 **PhD3: Detection, classification, identification and mitigation of GNSS signal degradations by means of ML** *Evgenii Munin*	12.00-12.30 **PhD9: Stochastic control of tactical airline operations in hub-airport networks** *Jan Evler*	16.15-17.00 **SESAR ER Case study 1: COCTA** *Radosav Jovanović*	15.45-17.00 **Tools for data science** *Gerald Gurtner*		
16.15-16.45 **PhD4: ML techniques for seamless traffic demand prediction** *Manuel Mateos*	13.30-15.00 **Introduction to air traffic control – part 1** *Fedja Netjasov*				
	15.30-17.00 **Introduction to air traffic control – part 2** *Fedja Netjasov*				
	17.00-17.15 **PhD contracts update** Graham Tanner				

Figure 2: 1st summer school programme, 09-13 September 2019

The summer school evolved in 2020 to a split approach, with approximately half of the week allocated to the PhD candidates acting as mutual discussants, in pairs, for presentations of their work, then at a relatively mature stage. The other half of the week comprised an opportunity for a number of industry presentations and methodological tutorials – all of which were closely tailored to the needs of the PhD

candidates, based on a survey of the students and supervisors, and on feedback from the Engage mentors assigned to each PhD, who also moderated the PhD discussant sessions. Figure 3 shows the 2nd summer school programme. Over 80 participants took part in this virtual event.

	1030-1100	1100-1145	1200-1245	Lunch break	1400-1445	1500-1545	1600-1645
Mon 21SEP	Opening Radosav Jovanović University of Belgrade-FTTE, summer school coordinator Andrew Cook University of Westminster, Engage KTN coordinator	Decision support system for airline operation control hub centre Jonas Langner, TU Braunschweig Expert discussant: Dirk Schaefer Student discussant: J. Evler	Machine learning techniques for seamless traffic demand prediction Manuel Mateos, Nommon / UPC Barcelona Expert discussant: Lorenzo Castelli Student discussant: S. Reyna		Mitigation of GNSS signal degradations by means of machine learning Evgenii Munin, ENAC Expert discussant: Junzi Sun Student discussant: H. Khaledian	Integrating weather prediction models into ATM planning Anastasia Lemetti, Linköping University Expert discussant: Tatjana Bolić Student discussant: E. Andrés	Conflict-free trajectories: a multi agent reinforcement learning approach Alevizos Bastas, University of Piraeus Expert discussant: Fedja Netjasov Student discussant: R. Isufaj
	0930-1015	1030-1115	1130-1215	Lunch break	1330-1415	1430-1515	1530-1615
Tue 22SEP	Automated DCB hotspot detection Sergi Mas Pujol, UPC Barcelona Expert discussant: Gérald Gurtner Evolution of route charging mechanisms Natalia Solčianska, University of Trieste Expert discussant: Radosav Jovanović	Stochastic control of tactical airline operations in hub airport networks Jan Evler, TU Dresden Expert discussant: Andrew Cook Student discussant: J. Langner	Second generation agent-based modelling for improving APOC operations Sashiko Shirai Reyna, Amsterdam UAS / ENAC Expert discussant: Bojana Mirković Student discussant: M. Mateos		Advanced statistical signal processing for next generation trajectory prediction Homeyra Khaledian, UPC Barcelona Expert discussant: Dirk Schaefer Student discussant: E. Munin	A pilot/dispatcher support tool based on the enhanced provision of thunderstorm forecasts Eduardo Andrés, Universidad Carlos III de Madrid Expert discussant: Luis Delgado Student discussant: A. Lemetti	Machine learning applications to extend AGENT's conflict resolution capabilities Ralvi Isufaj, Autonomous University of Barcelona Expert discussant: Fedja Netjasov Student discussant: A. Bastas
	0930-1015	1030-1130	1145-1245	Lunch break	1400-1500	1515-1600	1615-1700
Wed 23SEP	Opportunities in industry Insights into a PhD within an airline Marie Carré, SWISS International Air Lines The Talent Network at Frequentis Georg Trausmuth, Frequentis	Understanding the tactical control of aircraft Olivia Nunez, SESAR JU	Collaborative decision making in the APOC context, with case studies Alan Marsden, EUROCONTROL		EUROCONTROL data sources (Part 1) David Marsh, EUROCONTROL	Airline disruption management - data flows and decision-making processes Marie Carré, SWISS International Air Lines	EUROCONTROL data sources (Part 2) David Marsh, EUROCONTROL
	0930-1030	1045-1130	1145-1230	Lunch break	1400-1500	1515-1615	1630-1715
Thu 24SEP	Delays in European aviation - building passenger cost models Andrew Cook, University of Westminster	An interaction metric for an efficient traffic demand management Juan José Ramos, Aslogic Flight centric ATC with airstreams Georges Mykoniatis, ENAC	Exploring future UDPP concepts through computational behavioural economics David Mocholí, Nommon Role of Markets in AAS Deployment Maribel Tomás, Think Research		New architectures in ATM, and virtual centre development Ruben Flohr, SESAR JU	Short-term air traffic flow management integrating separation management and ground holding Bo Zou, University of Illinois at Chicago	The Quiz with a Difference
	0930-1030	1045-1145	1145-1215				
Fri 25SEP	Insights into flow management perspectives Lorna Herda, Skyguide	Applied machine-learning in ATM Laurent Nicolas & Olivier Carron, Innov'ATM	Wrap up and closing Radosav Jovanović & Andrew Cook		engagektn.com/summer-school-2020 PhD Industry Tutorial Quiz		

Figure 3: 2nd summer school programme, 21-25 September 2020

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The 2021 summer school saw a move to rather longer PhD presentations, grouped largely into thematic pairs, with subsequent extended panel discussions with domain experts from industry (see Figure 4). A particular focus was sought on how the work of the PhD could be taken forward in an operational/more applied setting. These combined sessions (PhD presentations followed by industry panels) were moderated by a member of the Engage team (a mentor of one or both of the Engage PhDs). This format dominated the summer school, although interspersed with some other sessions, and was met with significant positive feedback. Coordinating the thematic challenge workshop 'Machine learning, AI and automation in ATM' (see Table 2) on the final day of the summer school week, as a follow-on, but independent, event, also worked well in that it pursued a number of technical elements of the PhD topics, and attracted a good follow-on audience, plus new participants. Almost 100 participants attended the 3rd summer school.

	09.45-10.00	10.00-11.15	11.30-12.30		13.30-14.10	14.10-14.45	15.00-15.30	
MON 30AUG	Opening *Andrew Cook (UoW) & Lorenzo Castelli (University of Trieste)*	Airline and airport operations centres *Jonas Langner (TU Braunschweig), Sashiko Shirai Reyna (Amsterdam UAS/ENAC)*	Panel discussion Moderator: *Bojana Mirkovic (University of Belgrade-FTTE)*	Lunch break	Signal processing for trajectory prediction *Homeyra Khaledian (UPC Barcelona)*	Panel discussion Moderator: *Junzi Sun (TU Delft)*	SESAR Young Scientist Award *Junzi Sun (TU Delft)*	
		11.15-12.00	12.00-12.30		13.30-14.45	15.00-16.00		
TUE 31AUG		The Engage wiki *Pablo Hernandez (Innaxis)*	Teaching resources in the wiki *(University of Belgrade-FTTE*)*	Lunch break	DCB hotspot detection and machine learning for traffic demand prediction *Sergi Mas Pujol (UPC Barcelona), Manuel Mateos (Nommon/UPC Barcelona)*	Panel discussion Moderator: *Lorenzo Castelli (Uni. of Trieste)*		
		10.00-11.15	11.30-12.30		13.30-15.30	15.30-16.00		
WED 01SEP		Machine learning and traffic deconfliction *Alevizos Bastas (University of Piraeus), Ralvi Isufaj (UAB Barcelona)*	Panel discussion Moderator: *Fedja Netjasov (Belgrade-FTTE)*	Lunch break	Shaping a future European ATM Academy *SESAR Scientific Committee*	Engage PhDs Q&A *UoW*		
		10.00-11.15	11.30-12.30		13.30-14.45	15.00-16.00	16.15-17.00	17.00-17.15
THU 02SEP		Weather prediction / forecasting models *Anastasia Lemetti (Linköping University), Eduardo Andrés (Universidad Carlos III Madrid)*	Panel discussion Moderator: *Tatjana Bolic (University of Westminster)*	Lunch break	Flight prioritisation, UDPP and route charging *Jan Evler (TU Dresden), Andrea Gasparin (University of Trieste), Natalia Solčianska, (University of Trieste)*	Panel discussion Moderator: *Andrew Cook (University of Westminster)*	Future research horizons *Dirk Schaefer (EUROCONTROL)*	Close and what's coming next *Andrew Cook (UoW)*

Figure 4: 3rd summer school programme, 30 August – 02 September 2021

The three summer schools were reported in D5.12, D5.13 and D5.14.

Four thematic challenges were central to the network, the goal of which was to address research topics which were not contemporaneously (sufficiently) addressed by the SESAR research programme. Engage invited proposals for thematic challenges through a Call which was open between January and March 2018. 54 proposals were submitted by the ATM community and evaluated by the Awards Board, identifying six priority themes from which the top four were selected:

- TC1 Vulnerabilities and global security of the CNS/ATM system

  CNS/ATM components (e.g., ADS-B, SWIM, datalink, Asterix) of the current and future air transport system present vulnerabilities that could be used to perform an 'attack'. Further investigations are necessary to mitigate these vulnerabilities, moving towards a cyber-resilient system, fully characterising ATM data, its confidentiality, integrity and availability requirements. A better understanding of the safety-security trade-off is required. Additional security assessments for legacy systems are also needed to identify possible mitigating controls in order to improve cyber-resilience without having to replace and refit. Future systems security by design is essential: a new generation of systems architectures and

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applications should be explored to ensure confidentiality, cyber-resilience, fault tolerance, scalability, efficiency, flexibility and trust among data owners. Collaborative, security-related information exchange is essential to all actors in aviation. This is specially challenging in a multi-stakeholder, multi-system environment such as ATM, where confidentiality and trust are key.

- TC2 Data-driven trajectory prediction

  Accurate and reliable trajectory prediction (TP) is a fundamental requirement to support trajectory-based operations. Lack of advance information and the mismatch between planned and flown trajectories caused by operational uncertainties from airports, ATC interventions, and 'hidden' flight plan data (e.g., cost indexes, take-off weights) are important shortcomings of the present state of the art. New TP approaches, merging and analysing different sources of flight-relevant information, are expected to increase TP robustness and support a seamless transition between tools supporting ATFCM across the planning phases. The exploitation of historical data by means of machine learning, statistical signal processing and causal models could boost TP performance and enhance the TBO paradigm. Specific research domains include machine-learning techniques, the aggregation of probabilistic predictions, and the development of tools for the identification of flow-management 'hotspots'. These could be integrated into network and trajectory planning tools, leading to enhanced TP.

- TC3 Efficient provision and use of meteorological information in ATM

  The main objective of this challenge is to improve overall ATM system performance by providing better user-support tools based on improved meteorological ('met') products. The focus is on the synergy of several methods and techniques in order to better meet the needs of operational users and to support aviation safety (e.g., through creating early warning systems) and regulation-makers (e.g., moving from text-based to graphical information provision). All stakeholders may benefit from this synergy: ANSPs (e.g., sector reconfiguration and separation provision), airlines (e.g., storm avoidance), airport operators (e.g., airport management under disruptive events), and the Network Manager (e.g., demand-capacity balancing). The challenge is, therefore, to bring the following perspectives closer: (a) for meteorological/atmospheric science, the development of products tailored to ATM stakeholders' needs, which are unambiguous and easy to interpret; (b) for stakeholders, the identification of the most suitable information available and its integration into planning and decision-making processes.

- TC4 Novel and more effective allocation markets in ATM

  This research explores the design of new allocation markets in ATM, taking into account real stakeholder behaviours. It focuses on designs such as auctions and 'smart' contracts for slot and trajectory allocations. It seeks to better predict the actual behaviour of stakeholders, compared with behaviours predicted by normative models, taking into account that decisions are often made in the context of uncertainty. Which mechanisms are more robust against behavioural biases and likely to reach stable and efficient solutions, equitably building on existing SESAR practices? The research will address better modelling and measurement of these effects in ATM, taking account of 'irrational' agents such as airline 'cultures'. A key objective is to contribute to the development of improved tools to better manage the allocation of resources such as slots and trajectories, and incentivising behaviour that benefits the network – for example by investigating the potential of centralised markets and 'smart' contract enablers.

The four thematic challenges were supported by dedicated workshops organised by the consortium, which were held during the first four years of the network. Two sets of briefing notes were prepared as inputs to the thematic workshops, which were published on the Engage website (thematic challenges page) and were later collated in D5.6. The thematic challenges were subsequently reviewed mid-term, with the decision taken to retain all of them. The selection of the thematic challenges and preparation work for the workshops were reported in D3.4 (Thematic challenges priming report for first workshops).

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A strong attribute of the Engage KTN was its focus on the selection of thematic challenges that require further research efforts, also offering paths to the Engage PhDs and catalyst funded projects to address them.

The aim of **catalyst funding** was to further promote cooperation between industry and academia, between exploratory research and applied research, by funding focused projects, stimulating the transfer of ER results towards ATM application-oriented research. This funding was awarded to groups (e.g. an industry partner leading a thematic challenge with an academic institution working in an area bringing potential solutions to this thematic challenge) to conduct and fast-track specific activities in support of developing solutions to the challenges and moving closer towards industry goals and objectives, and towards higher technology readiness levels (TRLs).

Two Calls for catalyst funding projects, published by Engage in 2019 and in 2020, led to a total of over 40 proposals being received and evaluated by the Awards Board. Ten projects were selected for funding in the first wave, followed by a second wave of eight projects (a total of 31 unique institutions were involved across both waves). Each project ran for 12 months, focusing on maturing exploratory research further towards applications and operational contexts. CF projects participated in the workshops associated with their thematic challenge and each published a final technical report summarising their work and results (published on the catalyst fund project summaries and reporting page and reported in D4.1-D4.18). The CF project abstracts are available in Appendix B. Table 1 shows the number of CF projects within each thematic challenge, plus one 'open' project.

Table 1: Overview of catalyst fund projects per thematic challenge

Thematic challenge	CF1	CF2	Total
Open	0	1*	1
TC1 Vulnerabilities and global security of the CNS/ATM system	2	3	5
TC2 Data-driven trajectory prediction	3	1	4
TC3 Efficient provision and use of meteorological information in ATM	4	2	6
TC4 Novel and more effective allocation markets in ATM	1	1	2
Total	10	8	18

* Open project fit rather well, *post hoc*, within the TC2 stream.

A total of 14 **thematic challenge workshops** were organised by the consortium, which brought together a wide range of ER and IR researchers. Three workshops were held for TC1 and TC4, and four each for TC2 and TC3 (see Table 2). These were arranged as physical events before moving on-line during the pandemic. As the thematic challenges were closely linked with the catalyst funding, the goal of the first round of TC workshops was to collect conclusions to be included in the material for the catalyst funding Calls. The second round of workshops presented the catalyst funding (CF) projects from wave 1, and other appropriate research from the same thematic challenge areas. The goal of the third round of the TC workshops was to present the results from both the wave 1 and wave 2 CF projects. The fourth edition of workshops focused on identification of future research directions.

The format of the final workshops in 2021 were thus modified to keep the content pertinent and to maximise the return of new research ideas to feed D3.10. Material from all the workshops has been published on the Engage website (thematic challenges page), and the annual series of workshops were reported in D2.5, D2.6 and D2.7.

Table 2: Engage thematic challenge workshops

Thematic challenge	Workshop title	Date	Location	Participants/ registrations*
TC4 - 1st workshop	Novel and more effective allocation markets in ATM	25/10/2018	London	28
TC2 - 1st workshop	Data-driven trajectory prediction	06/11/2018	Barcelona	32
TC3 - 1st workshop	Efficient provision and use of meteorological information in ATM	13/11/2018	Brussels	26
TC1 - 1st workshop	Vulnerabilities and global security of the CNS/ATM system	27/03/2019	Brussels	42
TC3 - 2nd workshop	Efficient provision and use of meteorological information in ATM	05/11/2019	Brussels	17
TC4 - 2nd workshop	Novel and more effective allocation markets in ATM – the way forward	12/11/2019	Madrid	21
TC2 - 2nd workshop	Data-driven trajectory prediction	02/12/2019	Athens (co-located at the SIDs)	37
TC1 - 2nd workshop	Vulnerabilities and global security of the CNS/ATM system	10/11/2020	Virtual	59
TC2 - 3rd workshop	Data-driven trajectory prediction	25/01/2021	Virtual	66
TC3 - 3rd workshop	Efficient provision and use of meteorological information in ATM	27/01/2021	Virtual	70
TC4 - 3rd workshop	Economic incentives for future ATM implementation	21/06/2021	Virtual	67
TC2 - 4th workshop	AI, ML and Automation	03/09/2021	Virtual	117
TC3 - 4th workshop	Efficient provision and use of MET information in ATM	09/09/2021	Virtual	79
TC1 - 3rd workshop	Vulnerabilities and global security of the CNS/ATM system	15/09/2021	Virtual	72

* Participants at face-to-face events; registrations for virtual events.

The organisation of **four SESAR Innovation Days conferences** held during the timeframe of the KTN (2018-2021), received support and expertise from Engage consortium members. Engage support was led by EUROCONTROL, closely collaborating with the S3JU as the organiser of the event, and spanned initial planning through to post-conference activities. Engage support included organising and publicising the Call for Contributions (full papers and poster abstracts), leading the review and selection process and the preparation of the conference programme. Some of Engage's industry partners also had direct involvement, as members of the Programme Committee. Refer to D2.8, D2.9, D2.10 and D2.11 for annual Engage reporting of the SIDs.

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The **EngageWiki** [60] was launched in December 2020 during the 10th SESAR Innovation Days' closing session. User registration opened on the same day – any researcher or user could apply for a (free) authorised account to become an active member of SESAR's KTN community.

Key wiki features developed by the consortium include the interactive research map of European ATM, the ATM concepts roadmap, a consolidated listing of European university programmes and a new, one-stop (data) repository for the research community (further wiki features were developed). The interactive research map of European ATM (see Figure 5) allows users to explore the results of a bottom-up clustering from unsupervised machine learning applied to SESAR 1 and SESAR 2020 projects and papers.

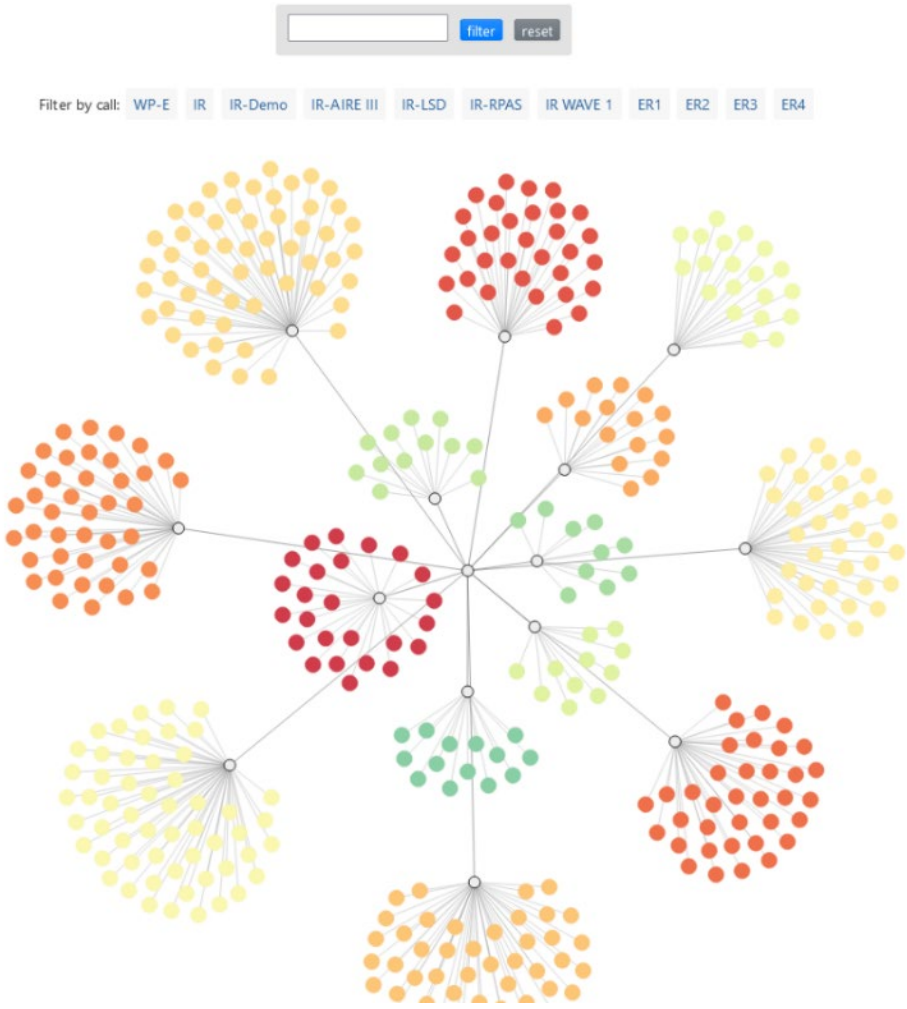

Figure 5: EngageWiki interactive research map of ATM

The ATM concepts roadmap (see Figure 6) shows how previous SESAR research connects with the flagship activities of the 2020 Strategic Research and Innovation Agenda (SRIA [119]), identifying future challenges.

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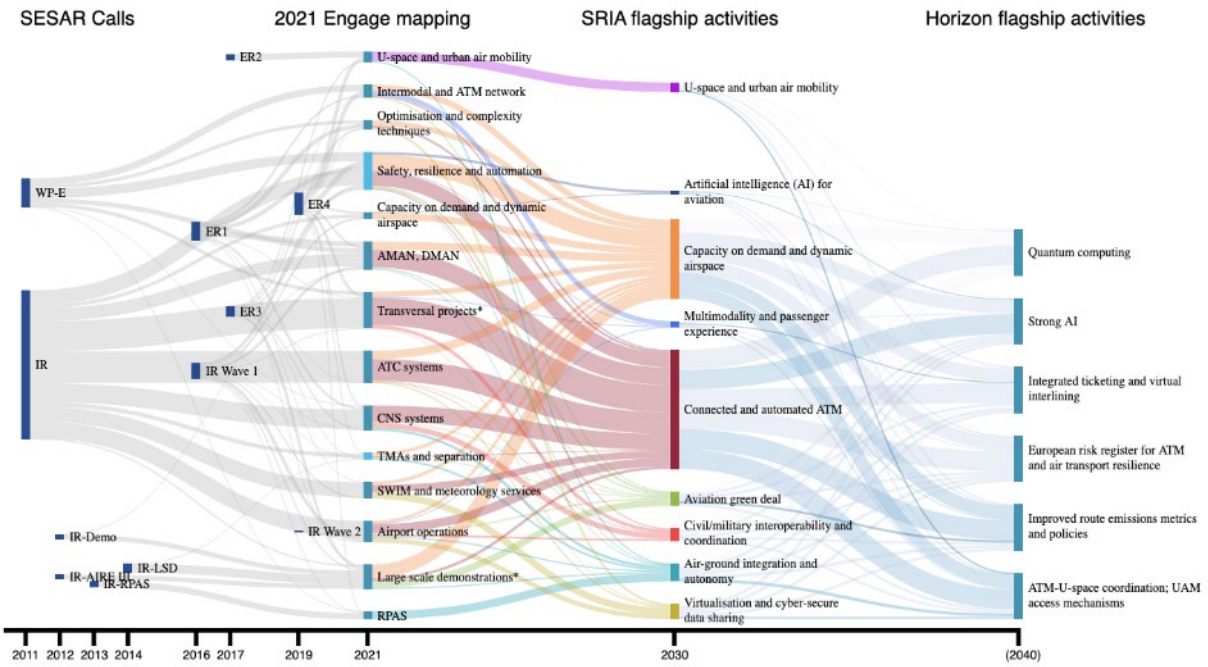

Figure 6: EngageWiki ATM concepts roadmap

D3.9 provides final reporting on the wiki (superseding the earlier D3.8), whilst key outputs and results enabled through the wiki, such as mapping research gaps, were discussed in D3.10, which focused specifically on opportunities for innovative ATM research. D3.10 highlighted future research opportunities for ATM, with the basic framework structured around three research pillars: **gap analysis**, **'horizon' flagships** and **thematic challenges** (the first two pillars complementing the TC pillar).

Gap analysis was used to identify potential research gaps, identifying future research directions. This was deployed as a phased combination of quantitative and qualitative analysis. An auto-encoder model (a special type of neural network) and multi-dimensional vectors were first used to extract key statistical information (e.g. keyword analysis, semantic similarity indices, outlier detection) from SESAR deliverables in order to identify areas potentially poorly covered in the SRIA [119] and yet with remaining potential interest to the research community. Secondly, these results were interpreted by ATM experts in the Engage consortium.

The **'horizon' flagships** looked further ahead. Engage set out to advance the definition of future research concepts and directions beyond what has already been published in the SRIA. The use of 'horizon' reflecting the familiar concept of horizon scanning in research, identifying future concepts. 'Flagship activities' was used as a complementary term to the SRIA 'flagship activities'. These ideas were conceived and developed by the consortium. The concepts had to be futuristic in the sense that they had not already been (fully) researched in the ATM domain, either through omission and/or because the underpinning principles (e.g. for quantum computing) continue to be at a very low TRL (level 0 or 1). These concepts did, however, at least have to map to some extent onto existing ATM activities in the SRIA: if they connected to none of these at all, it was difficult to justify their relevance to ATM, considering the relatively broad scope and maturity of the SRIA.

2.4 Key Project Results

Activities structured around the three research pillars were carried out at different times during the work of the KTN. The thematic challenges were launched in the first month of the KTN. The gap analysis and horizon flagship development during the later stages of the KTN. The following sub-sections summarise some of the key results, starting with the four thematic challenges.

Four thematic challenges

The following results for each thematic challenge were obtained from the third and fourth editions of the thematic challenge workshops held in 2021.

TC1 Vulnerabilities and global security of the CNS/ATM system

CNS/ATM components (e.g., ADS-B, SWIM, datalink, Asterix) of the current and future air transport system present vulnerabilities that could be used to perform an 'attack'. Further investigations are necessary to mitigate these vulnerabilities, moving towards a cyber-resilient system, fully characterising ATM data, its confidentiality, integrity and availability requirements. A better understanding of the safety-security trade-off is required. Additional security assessments for legacy systems are also needed to identify possible mitigating controls in order to improve cyber-resilience without having to replace and refit. Future systems security by design is essential: a new generation of systems architectures and applications should be explored to ensure confidentiality, cyber-resilience, fault tolerance, scalability, efficiency, flexibility and trust among data owners. Collaborative, security-related information exchange is essential to all actors in aviation. This is specially challenging in a multi-stakeholder, multi-system environment such as ATM, where confidentiality and trust are key.

Nevertheless, the cybersecurity awareness and security culture are still rather immature in ATM research. There is, however, much interest in addressing this topic and creating a SESAR cybersecurity community.

The final TC1 workshop presented the latest results from the Engage catalyst fund projects, advancing the state of the art on pentesting platforms, assured telemetry for U-Space, and collaborative cybersecurity management frameworks. This was followed by a discussion on the creation of a cyber-community and its networking needs ahead of SESAR 3. Subsequent discussion was dedicated to future cybersecurity work, from research and solution life-cycle perspectives. This was primed by the recommendations on cybersecurity for SESAR 3 produced by the SESAR 2020 Scientific Committee. The overall goal of the workshop was to identify what research infrastructure and future research themes could be proposed for SESAR 3, for example.

Responsible disclosure mechanisms (in cybersecurity) for the research community are particularly relevant. Such mechanisms are highly bureaucratic and troublesome, and should be improved, perhaps even with incentivisation at the European level. The area is complicated for researchers by some tech companies making use of cease-and-desist orders. This is a very complex topic in cybersecurity and data privacy in general.

To compensate for insufficient cybersecurity research in projects there is an opportunity for organising initiatives that increase knowledge and skills for ER participants in particular, in the form of masterclass sessions, that could be given through the SESAR Digital Academy, or a new KTN, if launched under SESAR 3. These could cover 'security by design' and address the low maturity of a security culture in

the general ATM community, instructing on the existence of security problems, the frequency of attacks and the ensuing effects of such attacks (which are often very costly). The quantification of the problem, in terms of financial impact, might be of help to raise security awareness and culture.

Topics flagged for future work related to cybersecurity:

- **Responsible disclosure**, in particular, and **sharing experimental scenarios**, in general, are significant challenges in this domain.
- Systematically **promoting awareness** and ensuring that cybersecurity considerations are at least taken into account from the **earliest (design) stages** of any development, in all projects, regardless of whether the focus is on cybersecurity or not.
- To investigate the use of ML and AI as a means of **automating certain parts of controllers' work** – what are the risks and how do you certify them?
- To investigate the use of ML and AI **penetration testing for industrial prototypes**, applying AI/ML to **strengthen systems** and render them less subject to cyber attacks. When using ML and AI in operational applications – what are the risks and how do you certify them?
- Considering the **ADS-B vulnerabilities** and the potential attacks it may suffer, additional effort, at higher TRLs, beyond research activities should be dedicated to developing **deployable solutions**, as the need for such solutions is becoming rather urgent.
- In the past, most resources have been allocated to safety development, and security has been rather neglected. For future research developments, cybersecurity can **leverage on the strong safety management** experience and culture. The SESAR Digital Academy, or a new KTN, could promote knowledge transfer.

TC2 Data-driven trajectory prediction (AI, ML and automation)

An interesting topic raised in these discussions was the fact that advisory systems change the environment in which advisories are provided, especially if many users use the same advisory system. This effect may be short-term, in the sense that if various controllers use a similar advisory system to solve one conflict, this specific conflict may become irrelevant, and in the worst case a new conflict may appear. It may also be long-term, in the sense that users may change their behaviour on the basis of the advice they receive from an assistant system. Triggered by this observation the question of **retraining ML systems** was discussed; a system trained in the lab will become less and less relevant as the environment for which it was trained evolves and may hence need to be retrained. Criteria for deciding when such a retraining is required are not yet established. If ML systems are continuously learning, such retraining is not required anymore, of course, yet the **certification process for continuously learning systems** will be much more demanding.

Performance assessment of trajectory prediction (e.g. on efficiency) is still to be matured. This would require agreement with all stakeholders, to try to find a common approach and to demonstrate the benefits of the developments. No common approach to KPA/KPI assessment seems to exist presently in the IR and ER projects, in this domain. The possibility of holding a specific workshop dedicated to performance measurement in this area, was suggested. Further work on both trajectory prediction and trajectory optimisation is still needed with regard to integration with maturing automation tools.

Explainability was frequently raised and whilst 'explainable AI' is now establishing itself as a discipline of artificial intelligence, some ML algorithms lend themselves more easily to explainability than others. Also, whilst it is easy to claim that all systems should be explainable, the practical value of the

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explanation for the use should be assessed, especially if there is a **trade-off between explainability and performance**, for example when two different ML models are compared. The trade-off between conformance and transparency (a concept closely related to explainability) will be studied in the MAHALO project.

Training ML systems on datasets where, for example, human conflict resolution is observed will lead to a **system that mimics human behaviour**; this leads to the question whether ML should be similar to, or perhaps better than, human decision making. The way ATCOs manage traffic and resolve conflicts depends on some constraints that are irrelevant for machines, for example memory, mental arithmetic and workload. Only mimicking human decision making may introduce a **bias in favour of present working patterns** rather than fully exploiting the potential of machines.

Workshops on ML and AI will invariably lead to a discussion about **data availability and quality**, and these were no different. However, two specific aspects seem noteworthy: firstly, the fact that the data mostly used to train advisory systems in air traffic control, for example conflict detection and resolution, are **'too clean, real-world traffic data'** in which conflicts have already been 'optimised' and largely removed, either by pre-tactical or tactical tools (flight planning, slot allocation, MTCD, STCA, etc.) – so the very object of CD&R systems have largely been removed from the data. Secondly, in many cases, the data that can be recorded in experiments, or available in real-world observations, are not sufficient to satisfy the requirements of ML systems and hence **artificial training datasets** may be an option. Generating these, e.g. by mirroring existing scenarios or introducing noise, comes at a cost, which needs to be considered.

The next steps and prerequisites of an **uptake by industry** and application of ML systems in real-world applications was discussed and it was suggested to **distinguish** between **safety-critical** and **non-safety-critical** applications, as the latter are much more easily certifiable and deployable and allow carrying lessons learned over to the next phase when safety-critical applications will be targeted.

TC3 Efficient provision and use of MET information in ATM

Again, in this series of workshops, data access and sharing were cited as a problem. Specifically, in the MET context, is the issue of acquiring homogenised data for the entire European airspace (e.g., generic MET data, GNSS, lightning). The general discussion that follows is split between future research needs and those regarding speeding up the time from research to implementation.

(a) Future research needs

Climate impact: mitigation and metrics. Climate change and how it relates to aviation is a hot topic. There are different facets of the climate, and the impact of aviation on climate that still need to be researched, which require further multidisciplinary effort. In particular, for aviation climate impact, several sources of uncertainty need to be addressed in order to measure this properly. First, how to measure the impact should be addressed, as so far only CO_2 proxies are being used, and all other emissions measurements are in lower maturity research stages. Next, it is important to have a way of representing the behaviour of the atmosphere as linked to aviation emissions, on the timescales appropriate for their intended use. This links closely to the importance of defining new environmental indicators. The SES II+ package retains the same indicators as before (CO_2) and it is expected that CO_2 will thus drive the behaviour of ANSPs, as they are bound by these indicators. However, the climate is much more complicated, and requires additional metrics.

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Whilst various research topics were discussed, here we list those most emphasised:

- There is a need to continue to focus on the **uncertainties** of both **weather forecasts and climate research**, especially on how to deal with them in models and metrics. Further multidisciplinary effort is required to address this, building on solid existing ER work.
- Forecasting **of extreme weather events** is a key issue for aviation.
- An **educational component** in both the scoping of tool requirements and the implementation and use of the MET tools or services is required. The SESAR Digital Academy, or a new KTN, could promote such knowledge transfer.
- The **weather impact on (small) drone operations** needs further investigation:
    - measuring weather for drones (resolution and update rate of weather);
    - modelling the weather in the urban environment (urban weather is different compared with open space);
    - communicating weather information from the sources to the users, which needs firm standards on how this information should be communicated;
    - drone operators are less trained compared to ATCOs or pilots, so these tools need to be extremely easy to use.

(b) From research to implementation

Several issues were shared across the needs for future research and on speeding up the time from research to implementation.

- The **European Green Deal**[2], and other environmental initiatives, require that environmental sustainability is addressed in all sectors, aviation included. Due to the nature of the problem in aviation, it is important to find an appropriate means to address and implement it. The proposed mechanisms range from regulatory to market-based, and more research is needed to be able to make an informed choice.
- To best address weather impacts on the air transport network, a proactive approach should be applied. Such an approach should involve all stakeholders, in a joint effort, striving to reach the best decisions based on available data and services. For a **proactive approach** to be successful, educational components (e.g. a **common interpretation** of the weather data by stakeholders, as it relates to their operational needs) need to be an integral part thereof.
- Extraction of **end-user requirements** for (tailored) MET services remains an important matter, as this impacts heavily on the utility of the MET service in operations.
- The path to agree on **MET regulations** globally is steered by ICAO, which often may be perceived as **rather slow**. There are good reasons for wishing to speed up the procedure. Conversely, it is important that regulations are accepted globally, to avoid wholly uncoordinated information provision (e.g., different types of MET services, formats, etc.), making it impossible for end-users to have common MET information, complicating further the decision-making processes.

[2] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

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TC4 Economic incentives for future ATM implementation

Prior to the workshop, which was based centrally on the RoMiAD catalyst fund project (run by Think Research Ltd), Think's white paper was distributed , which set the scene for the discussion well: "The Airspace Architecture Study (AAS) proposed a transition to a distributed architecture enabling significant performance increases in the European Air Traffic Management (ATM) system. Successful transition requires service providers to adopt new technologies, operational concepts, and business models. The proposed architecture is based on three operational layers including the notion of a new form of service provider– the ATM Data Services Provider (ADSP) - which would enable certain services currently provided within an area control centre to be provided remotely. This white paper is a summary of the findings of Project RoMiAD (Role of Markets in AAS Deployment) – catalyst fund project of SESAR's Engage Knowledge Transfer Network, which considered how ATM cost efficiency can be increased through adoption of the AAS architecture and how the necessary transition can be incentivised."

A clear message from these discussions was that planned changes in ATM will not only be about technological innovation. The change will include regulatory, organisational, and service evolution. To achieve the largest benefits for the system, the emphasis should be on speed of uptake, and those stakeholders that want to move quickly should be supported to do so. **A framework that enables early adopters (progressive stakeholders) to move quickly is needed. When we talk about positive change, we should adopt a broader view regarding incentives**. Incentives do not necessarily need to be only economic, but also look into socio-organisational/behavioural ones. For example, **different social norms,** such as peer-group performance. The behaviour of individuals can often be surprising, sometimes counterintuitive, but can often help in speeding up the adoption of innovations.

Liability matters should be clearly defined. How liability issues impact the assurance of the end-to-end provision of ATS should be analysed in depth. Furthermore, the requirements for ADSPs (i.e. regarding operations and certification) should be created in such a way that they become common across the Single European Sky (SES).

The **question of the certification of data providers** might arise in future. This may precipitate questions on what to certify, and possibly even sovereignty matters. **The challenge lies in showing that the end-to-end solution is satisfactory for the regulator,** thus demonstrating resilience. The main issue in this type of integration lies in the consolidation of information for the ATCO. Does the virtualisation provider need to be certified, or would it be enough that ANSPs confirm that the service is appropriate? Service is appropriate when ANSPs can provide the ATS service with the appropriate quality. Should we be looking at the qualification, not certification? Furthermore, on the **sovereignty matter, there is the issue of what data needs to be within a given State.** Some ANSPs already found ways and means to collaborate: instituting this collaboration as a service, as a way forward, is vital.

Further data-related issues centre around **how to interact with data and how to use data to deliver benefits** from such usage. It seems, currently, that the fear of misuse, and similar issues, is much higher than the use actually requires. **Data availability and proprietary licencing** could be significant barriers to the creation of **flexible services** – i.e. whereby access to data is limited behind cost and disclosure walls. Currently, almost all data in ATM are considered in need of being protected, which is not necessarily true. An analysis of what data should be protected and what should be available is needed, as this is one of the cornerstones of the airspace architecture study.

EUROCONTROL's Think Paper #14 [115] poses the question: after 50 years, is the joint pan-European system of route charges still fit for purpose? The key findings are:

- For 50 years, the Route Charges System has shown its flexibility to successfully adapt to an evolving air navigation services landscape.
- Efforts should continue to focus on cost-effective provision of air navigation services – pre-pandemic, actual and nominal costs remained steady for 11 years prior to the pandemic in a period when traffic has risen by 30%.
- The prolonged Covid pandemic has triggered questions about the user pays principle, in particular in view of the overall role in aviation in a crisis as deep as this one. If in 2020 airlines flew around 50% of their expected flights, they could through the spreading of unpaid 2020 costs end up paying for close to 100% of their planned flights.
- When traffic returns, the European network will also once again be confronted with the pre-pandemic challenges of capacity and delays and environmental considerations. Charging policies that can help tackle these challenges should be considered when possible.
- The main challenge for the Route Charges System is to keep a common policy while evolving and accommodating traffic, capacity and environmental challenges.
- Single European Sky options such as a single unit rate and/or modulation of charges should be considered.

EngageWiki material

Results enabled through the wiki, such as mapping research gaps, are discussed later in this section under 'gap analysis'. Data requirements for these analyses and for wiki features such as the interactive research map (see Figure 5) consisted primarily of SESAR 1 and SESAR 2020 project deliverables, Solution data packs and conference papers along with associated metadata describing each project, deliverable and conference paper. **1873 deliverables from 426 projects were obtained** at the time of the last major wiki update (2021), as shown in the following table.

Table 3: SESAR material

SESAR programme	Calls	Projects	Deliverables
SESAR1	IR	226	775
	IR-AIRE III	7	7
	IR-Demo	8	8
	IR-LSD	14	15
	IR-RPAS	9	9
	WP-E	43	157
SESAR 2020	IR Wave 1	24	224
	IR Wave 2	2	10
	ER1	28	242
	ER2	9	99
	ER3	16	172
	ER4	40	155
Total	**12**	**426**	**1873**

In parallel to the sourcing of SESAR deliverables, conference papers presented at the SESAR Innovation Days and the USA/Europe ATM Research and Development Seminars (ATM Seminar) were collated with the assistance of EUROCONTROL. As shown in Table 4 and Table 5, a total of **310 SIDs papers** (2011-2020) and **343 ATM Seminar papers** (2011-2019) have been made available in the wiki. Known associations with SESAR projects were identified, e.g. of the 34 papers presented at the 2018 edition of the SIDs, 9 papers were associated with ER1 projects, and 1 each for ER2 and ER3 projects. Project associations have yet to be determined for ATM Seminar papers. Note that the anonymisation of published conference papers is neither required nor desirable.

Table 4: SIDs papers sourced and matched with SESAR projects

SIDs	Total Papers	Papers associated with projects*
2011	28	17 WP-E
2012	27	14 WP-E; 1 IR
2013	28	13 WP-E; 1 IR
2014	30	19 WP-E; 2 IR
2015	28	17 WP-E; 1 IR
2016	32	3 WP-E; 2 IR; 6 ER1
2017	35	20 ER1
2018	34	9 ER1; 1 ER2; 1 ER3
2019	38	1 ER1; 4 ER3; 6 IR Wave 1
2020	30	10 ER3

* SIDs papers determined to be associated with SESAR projects; SESAR projects in scope (i.e. papers from non-SESAR projects have also been identified, but are not in scope here); more than one paper per project could be accepted at each SIDs.

Table 5: ATM Seminar papers sourced

ATM seminars	Total papers
2011	69
2013	67
2015	69
2017	72
2019	66

Four editions of the SESAR Innovation Days

Engage has contributed to the success of the SESAR Innovation Days, with **330, 397, 1060 and 758 participants** at the four editions between 2018 and 2021 (the latter two conferences held virtually). The 2021 edition of the conference was successful in attracting the involvement and presence of representatives of industry and the European Commission. In many cases, dialogue between industry representatives and researchers has led to very tangible, beneficial outcomes.

The SIDs' triple peer-review process was reinforced with Engage industry partners which turned out to be particularly helpful. Many indicators related to the scientific content, such as the number of

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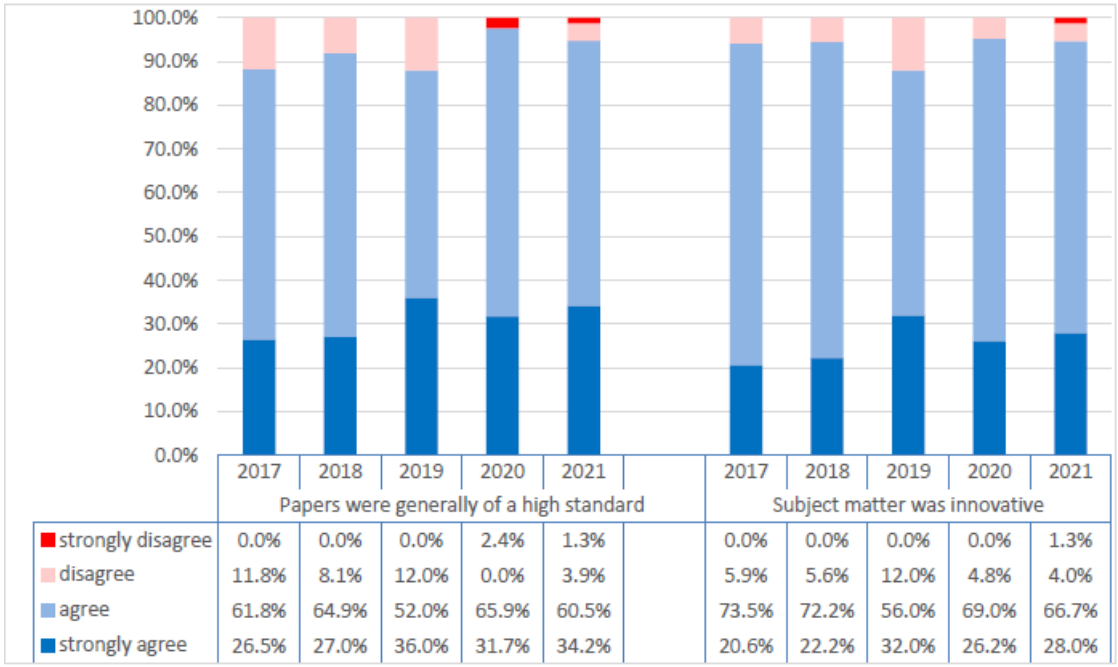
submissions (76 in 2021, four conference average of 64) and acceptance rate[3] (49% in 2021, four conference average of 56%) and the survey results related to the conference content (Figure 7 and Figure 8 reproduced from [11]) show that the SIDs are now an established and recognised scientific event, at which many SESAR and non-SESAR research projects choose to disseminate their results.



	Papers were generally of a high standard					Subject matter was innovative				
	2017	2018	2019	2020	2021	2017	2018	2019	2020	2021
strongly disagree	0.0%	0.0%	0.0%	2.4%	1.3%	0.0%	0.0%	0.0%	0.0%	1.3%
disagree	11.8%	8.1%	12.0%	0.0%	3.9%	5.9%	5.6%	12.0%	4.8%	4.0%
agree	61.8%	64.9%	52.0%	65.9%	60.5%	73.5%	72.2%	56.0%	69.0%	66.7%
strongly agree	26.5%	27.0%	36.0%	31.7%	34.2%	20.6%	22.2%	32.0%	26.2%	28.0%

Figure 7: SIDs 2021 survey 'Papers were generally of a high standard' and 'Subject matter was innovative'

[3] As noted in D2.11, the paper acceptance rate is an important quality indicator of scientific conferences; too high an acceptance rate suggests that submissions of poor quality are accepted; on the other hand, too low acceptance rates could discourage authors from submitting to a conference.

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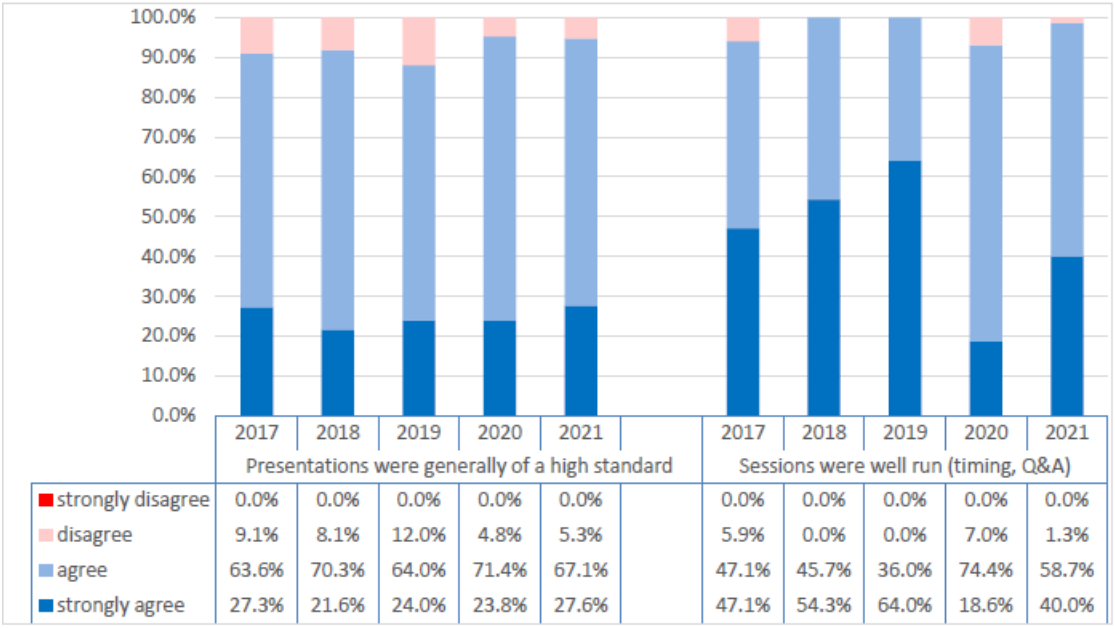

	2017	2018	2019	2020	2021	2017	2018	2019	2020	2021
	Presentations were generally of a high standard					Sessions were well run (timing, Q&A)				
strongly disagree	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
disagree	9.1%	8.1%	12.0%	4.8%	5.3%	5.9%	0.0%	0.0%	7.0%	1.3%
agree	63.6%	70.3%	64.0%	71.4%	67.1%	47.1%	45.7%	36.0%	74.4%	58.7%
strongly agree	27.3%	21.6%	24.0%	23.8%	27.6%	47.1%	54.3%	64.0%	18.6%	40.0%

Figure 8: SIDs 2021 survey 'Presentations were generally of a high standard' and 'Sessions were well run (timing, Q&A)'

Three European summer schools

Over 200 participants attended the three summer schools held in Belgrade (2019) and as virtual events (2020, 2021). These included the Engage PhD candidates, EUROCONTROL-sponsored PhDs, PhDs working on ER projects, postgraduate students, junior researchers and others from industry and consultancy.

Overall, the evolving summer school format across the three years (see Section 2.3), geared to meet the changing needs of the PhD candidates, including other PhD candidates in the same process, and closely knit with the additional, dedicated mentoring support and ad hoc technical workshops provided by Engage (e.g. on data sources and data management), has apparently been successful, as reflected in the feedback received, to the extent that the Engage consortium recommends a similar approach to the SESAR 3 KTN, should this also comprise a similar package of supported PhDs.

Nine PhDs completing their studies

With an objective of supporting European ATM education and training in the ATM community to develop new talent with a deep knowledge of the future ATM scientific research need, Engage funded and supported ten PhD candidates, nine of whom are in the process of completing their studies. Other non-Engage PhDs were also active within the KTN, participating at workshops and summer schools. Table 6 shows the PhD titles and institutions, with final abstracts available in Appendix B.

Table 6: Engage PhDs

PhD	Thematic challenge	PhD title	Institution
1	-	Decision support system for airline operation control hub centre ('DiSpAtCH')	Technische Universität Braunschweig (TUBS)
2	TC2	Trajectory planning for conflict-free trajectories: a multi agent reinforcement learning approach ('RL4CFTP')	University of Piraeus Research Center (UPRC)
3	-	Detection, classification, identification and mitigation of GNSS signal degradations by means of machine learning	Ecole Nationale de l'Aviation Civile (ENAC)
4	TC2	Machine learning for aircraft trajectory prediction: a solution for pre-tactical air traffic flow and capacity management	Nommon Solutions and Technologies and Universtitat Politècnica de Catalunya (UPC)
5	TC2	Deep Multi-Agent Reinforcement Learning Applications in ATM	Universitat Autònoma de Barcelona (UAB)
6	TC2, TC3	Integrating weather prediction models into ATM planning ('IWA')	Linköping University (LiU)
7	TC2	Advanced statistical signal processing for next generation trajectory prediction	Universitat Politècnica de Catalunya (UPC)
8	TC3	A pilot/dispatcher support tool based on the enhanced provision of thunderstorm forecasts considering its inherent uncertainty ('STORMY')	Universidad Carlos III de Madrid (UC3M)
9	TC4	2nd generation agent-based modelling for improving APOC operations	Stichting Hogeschool van Amsterdam (Amsterdam University of Applied Sciences - AUAS) and Ecole Nationale de l'Aviation Civile (ENAC)
10	TC4	Resource-Constrained Airline Ground Operations: Optimizing Schedule Recovery under Uncertainty	Technische Universität Dresden

By the close of the KTN, **PhDs had produced 106 outputs**, which included 11 journal articles, 28 conference papers and 49 presentations or posters (as summarised in Table 7). Additionally, each Engage PhD candidate prepared a final report which summarised their research and results (including a report covering the work of the non-completing candidate) which were published ahead of their PhD theses (see PhD abstracts and final reports page and D5.18-D5.27). Note that the PhD theses can be accessed from the hosting institutions (see PhD final reports for links). The full list of open access academic articles and conference papers published by PhDs (and CF projects) are shown in Table 10 and Table 11 respectively; these publications are also listed in Section 5.2.

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Table 7: Outputs from PhDs supported by Engage

Type of output	Number of outputs
Journal articles	11
Other articles, book chapters, working papers	6
Conference papers	28
Presentations, posters	49
Reports	10
Code	2
Total	**106**

18 catalyst fund projects

Engage funded 18 catalyst fund projects, each with a focus on maturing exploratory research further towards applications and operational contexts. The projects were able to address the corresponding thematic challenges (with one 'open' project which fitted rather well within TC2). Linked with the thematic challenge pillar, CF project results were presented at TC workshops or the 11th edition of the SIDs conference. Wave 1 final presentations are documented in D3.1, whilst wave 2 final presentations are available in D3.2. Table 8 shows the projects and consortia, with final abstracts available in Appendix B.

Table 8: Engage CF projects

Project	Thematic challenge	Project title	Consortium (coordinator; partners)
C1	TC3	Probabilistic weather avoidance routes for medium-term storm avoidance ('PSA-Met')	Universidad de Sevilla; MeteoSolutions GmbH
C2	TC3	airport-sCAle seveRe weather nowcastinG project ('CARGO')	Università degli Studi di Padova; LMU Munich; GReD srl; Leonardo GmbH
C3	TC1	Authentication and integrity for ADS-B	TU Kaiserslautern; SeRo Systems GmbH
C4	TC2	Data-driven trajectory imitation with reinforcement learning	University of Piraeus Research Center; Boeing Research and Technology Europe
C5	TC2	A Data-drIven approach for dynamic and Adaptive trajectory PredictiON ('DIAPasON')	CRIDA; Deep Blue; ZenaByte
C6	TC3	Operational alert Products for ATM via SWIM ('OPAS')	Royal Belgian Institute for Space Aeronomy
C7	TC2	An interaction metric for an efficient traffic demand management: requirements for the design of data-driven protection mechanisms ('INTERFACING')	Aslogic 2011 S.L.

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Project	Thematic challenge	Project title	Consortium (coordinator; partners)
C8	TC3	MET enhanced ATFCM	France Aviation Civile Services; MetSafe
C9	TC4	Exploring future UDPP concepts through computational behavioural economics	Nommon Solutions and Technologies
C10	TC1	The drone identity - investigating forensic-readiness of U-Space services	Open University; NATS
C11	TC1	Proof-of-concept: practical, flexible, affordable pentesting platform for ATM/avionics cybersecurity ('ATM-cybersec')	University of Jyväskylä
C12	TC1	Safe drone flight - assuring telemetry data integrity in U-Space scenarios ('SDF')	NATS; Open University
C13	Open	Flight centric ATC with airstreams ('FC2A')	NEOMETSYS; ENAC
C14	TC3	Meteo Sensors In the Sky ('METSIS')	NLR; AirHub B.V.
C15	TC2	Probabilistic information Integration in Uncertain data processing for Trajectory Prediction ('PIU4TP')	CIRA
C16	TC1	Collaborative cyber security management framework	Winsland Ltd; Movable-type; MSDK; BULATSA
C17	TC4	Role of Markets in AAS Deployment ('RoMiAD')	Think Research Ltd
C18	TC3	Weather impact prediction for ATFCM ('WIPA')	France Aviation Civile Services; MetSafe

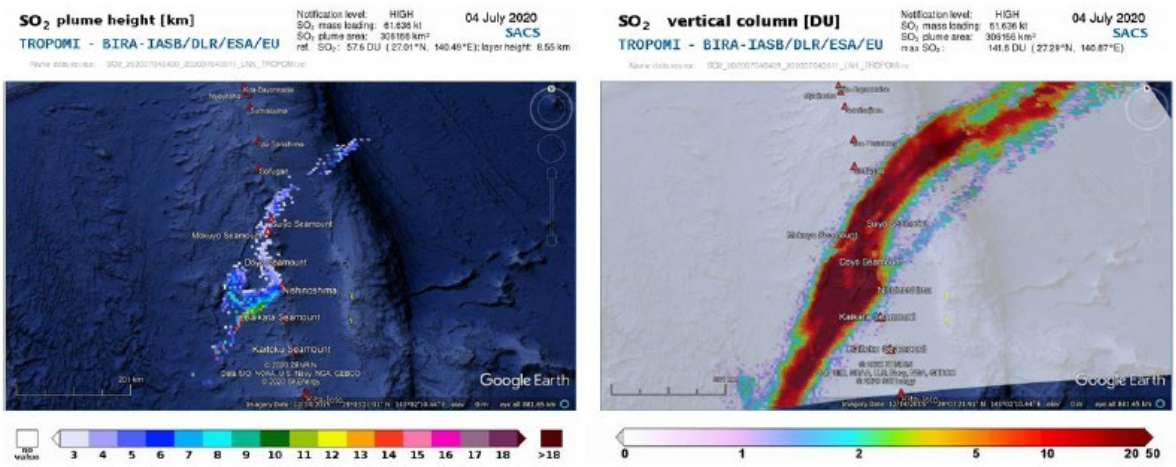
Each project also prepared a public final technical report of a high standard (see catalyst fund project summaries and reporting page and D4.1-D4.18). In total, **CF projects produced 129 outputs**, including 4 journal articles, 12 conference papers and an impressive 64 presentations (and posters/brochures) – these are summarised in Table 9. The full list of open access academic articles and conference papers published by CFs projects (and PhDs) are shown in Table 10 and Table 11 respectively; these publications are also listed in Section 5.2.

Table 9: Outputs from CF projects supported by Engage

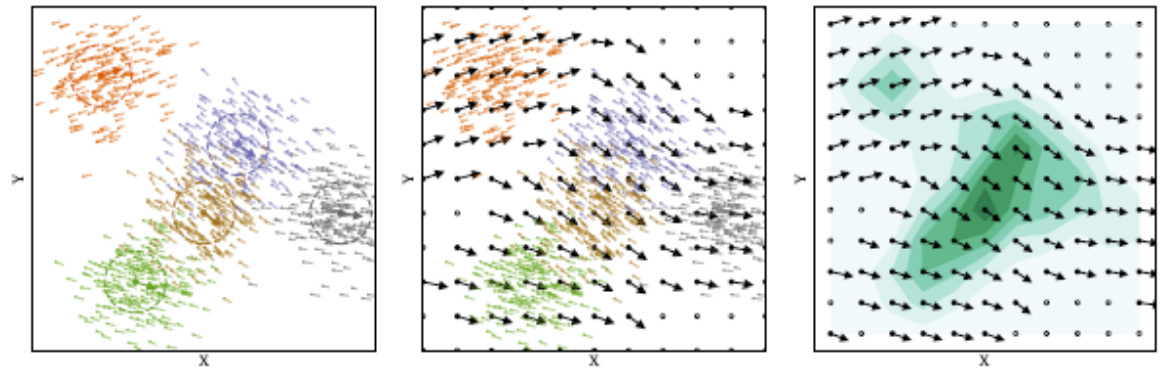
Type of output	Number of outputs
Journal articles*	4
Other articles, book chapters, white papers	4
Conference papers	12
Presentations, posters, brochures	64
Reports	24
Dissemination, videos	17
Demonstrations, tools	3
Code	1
Total	**129**

* Includes a paper that was co-authored by a PhD candidate; listed only here to avoid duplication.

Figure 9 shows examples of results presented by the 'OPAS' (wave 1) and 'METSIS' (wave 2) projects.



Operational alert Products for ATM via SWIM ('OPAS') project, showing tailored images from the sulphur dioxide height notification (source [26]])



(a) Wind observations and particle initialization (b) Wind field constructed from particles (c) Construction of estimation confidence

Meteo Sensors In the Sky ('METSIS') project, showing Meteo-Particle model key processes (source [104])

Figure 9: Examples of results from two catalyst fund projects

There are plans in place for CF project results to be tested through industrial applications, such as NATS' 'Safe Drone Flight' project. The France Aviation Civile Services-led CF wave 1 'MET Enhanced ATFCM' project results have been exploited by a SWIM webservice, and their follow-on wave 2 'WIPA' project's results have already been industrialised within VigiAero – an operational ATFCM weather-impact service, by consortium partner MetSafe.

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Following the extension of CF wave 1 project results into a number of ER4 projects, such as 'ALARM' and 'SINOPTICA', it is anticipated that CF wave 2 project results will also be extended into larger exploratory research projects, funded through future Calls.

Academic publications

Engage has supported the production of **50 open access publications** by PhDs and CF projects. These outputs have been reported via the European Commission's Portal so they will be available among Engage results in CORDIS [61].

Table 10 lists open access academic articles and journal papers, whilst Table 11 lists conference papers; these publications are also listed in Section 5.2.

Table 10: Academic articles and journal papers supported by Engage

PhD student / CF project	Authors	Title	Title of the journal / proceedings / book	Year / open access
CF	Yijun Yu, Danny Barthaud, Blaine A. Price, Arosha K. Bandara, Andrea Zisman, Bashar Nuseibeh	LiveBox: A Self-Adaptive Forensic-Ready Service for Drones	IEEE Access, Vol. 7	2019 / green
http://dx.doi.org/doi:10.1109/ACCESS.2019.2942033				
CF and PhD	Alevizos Bastas, Theocharis Kravaris, George A Vouros	Data Driven Aircraft Trajectory Prediction with Deep Imitation Learning	arXiv eprint	2020 / green
https://arxiv.org/abs/2005.07960				
PhD	Ralvi Isufaj, Thimjo Koca, Miquel Angel Piera	Spatiotemporal Graph Indicators for Air Traffic Complexity Analysis	Aerospace, Vol. 8	2021 / gold
https://doi.org/10.3390/aerospace8120364				
CF	Syed Khandker, Hannu Turtiainen, Andrei Costin, Timo Hamalainen	Cybersecurity attacks on software logic and error handling within ADS-B implementations: Systematic testing of resilience and countermeasures	IEEE Transactions on Aerospace and Electronic Systems, Vol. 58	2021 / green
https://doi.org/10.1109/TAES.2021.3139559				
PhD	Jan Evler, Ehsan Asadi, Henning Preis, Hartmut Fricke	Airline Ground Operations: Optimal Schedule Recovery with Uncertain Arrival Times	Journal of Air Transport Management, Vol. 92	2021 / gold
https://doi.org/10.1016/j.jairtraman.2021.102021				
PhD	Jan Evler, Ehsan Asadi, Henning Preis, Hartmut Fricke	Airline ground operations: Schedule recovery optimization approach with constrained resources	Transportation Research Part C: Emerging Technologies, Vol. 128	2021 / gold
https://doi.org/10.1016/j.trc.2021.103129				
PhD	Eduardo Andrés, Daniel González-Arribas, Manuel Soler, Maryam Kamgarpour, Manuel Sanjurjo-Rivo	Informed scenario-based RRT* for aircraft trajectory planning under ensemble forecasting of thunderstorms	Transportation Research Part C: Emerging Technologies, Vol. 129	2021 / gold
https://doi.org/10.1016/j.trc.2021.103232				

PhD student / CF project	Authors	Title	Title of the journal / proceedings / book	Year / open access
CF	Álvaro Rodríguez-Sanz, José Manuel Cordero García, Icíar García Ovies-Carro, Enrique Iglesias	A data-driven approach for dynamic and adaptive aircraft trajectory prediction	Transportation Research Procedia, Vol. 58	2021 / gold
https://doi.org/10.1016/j.trpro.2021.11.002				
PhD	Sergi Mas-Pujol, Esther Salamí, Enric Pastor	RNN-CNN hybrid model to predict C-ATC CAPACITY regulations for en-route traffic	Aerospace, Vol. 9	2022 / gold
https://doi.org/10.3390/aerospace9020093				
PhD	Ralvi Isufaj, Marsel Omeri, Miquel Angel Piera	Multi-UAV Conflict Resolution with Graph Convolutional Reinforcement Learning	Applied Sciences, Vol. 12	2022 / gold
https://doi.org/10.3390/app12020610				
PhD	Antoine Blais, Nicolas Couellan, Evgenii Munin	A novel image representation of GNSS correlation for deep learning multipath detection	Array, Vol. 14	2022 / gold
https://doi.org/10.1016/j.array.2022.100167				
PhD	Alevizos Bastas, George A Vouros	Data-driven prediction of Air Traffic Controllers reactions to resolving trajectory conflicts	arXiv eprint	2022 / green
https://arxiv.org/abs/2205.09539				
PhD	Jan Evler, Martin Lindner, Hartmut Fricke, Michael Schultz	Integration of Turnaround and Aircraft Recovery to Mitigate Delay Propagation in Airline Networks	Computers and Operations Research, Vol. 138	2022 / gold
https://doi.org/10.1016/j.cor.2021.105602				
PhD	Eulalia Hernández-Romero, Billy Josefsson, Anastasia Lemetti, Tatiana Polishchuk, Christiane Schmidt	Integrating weather impact in air traffic controller shift scheduling in remote and conventional towers	EURO Journal on Transportation and Logistics, Vol. 11	2022 / gold
https://doi.org/10.1016/j.ejtl.2022.100076				
CF	Hannu Turtiainen, Andrei Costin, Syed Khandker, Timo Hamalainen	GDL90fuzz: Fuzzing - GDL-90 Data Interface Specification Within Aviation Software and Avionics Devices–A Cybersecurity Pentesting Perspective	IEEE Access, Vol. 10	2022 / green
https://doi.org/10.1109/access.2022.3150840				
PhD	Marsel Omeri, Ralvi Isufaj, Romualdo Moreno Ortiz	Quantifying Well Clear for autonomous small UAS	IEEE Access, Vol. 10	2022 / green
https://doi.org/10.1109/access.2022.3186025				
PhD	Jan Evler, Michael Schultz, Hartmut Fricke, Andrew Cook	Stochastic Delay Cost Functions to Estimate Delay Propagation Under Uncertainty	IEEE Access, Vol. 10	2022 / green
https://doi.org/10.1109/access.2022.3152570				

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Table 11: Conference papers supported by Engage

PhD student / CF project	Authors	Title	Title of the journal / proceedings / book	Year / open access
PhD	Evgenii Munin, Antoine Blais, Nicolas Couellan	Convolutional Neural Network for Multipath Detection in GNSS Receivers	arXiv eprint	2019 / green
https://arxiv.org/abs/1911.02347				
CF	Yixing Luo, Yijun Yu, Zhi Jin, Haiyan Zhao	Environment-Centric Safety Requirements for Autonomous Unmanned Systems	Proceedings of the 27th IEEE International Requirements Engineering Conference	2019 / green
https://oro.open.ac.uk/62308/				
CF	Paulo Maia, Lucas Vieira, Matheus Chagas, Yijun Yu, Andrea Zisman, Bashar Nuseibeh	Cautious Adaptation of Defiant Components	Proceedings of the 34th IEEE/ACM International Conference on Automated Software Engineering	2019 / green
http://oro.open.ac.uk/66811				
PhD	Tatiana Polishchuk, Anastasia Lemetti, Raúl Sáez	Evaluation of flight efficiency for Stockholm Arlanda Airport using OpenSky Network data	Proceedings of the 7th OpenSky Workshop 2019	2019 / green
https://doi.org/10.29007/9g31				
PhD	Thimjo Koca, Ralvi Isufaj, Miquel Angel Piera	Strategies to Mitigate Tight Spatial Bounds Between Conflicts in Dense Traffic Situations	Proceedings of the 9th SESAR Innovation Days	2019 / green
https://www.sesarju.eu/sites/default/files/documents/sid/2019/papers/SIDs_2019_paper_82.pdf				
CF	Antonio Franco, Alfonso Valenzuela, Damián Rivas, Daniel Sacher, Jürgen Lang, Thomas Hauf	A Probabilistic Storm Avoidance Concept for En-Route Flight	Proceedings of the 10th SESAR Innovation Days	2020 / green
https://www.sesarju.eu/sites/default/files/documents/sid/2020/papers/SIDs_2020_paper_16red.pdf				
PhD	Anastasia Lemetti, Tatiana Polishchuk, Henrik Hardell	Arrival Flight Efficiency in Numbers: What New the Covid-19 Crisis is Bringing to the Picture?	Proceedings of the 10th SESAR Innovation Days	2020 / green
https://weber.itn.liu.se/~tatpo46/pps/SIDs2020_Covid.pdf				
PhD	Jan Evler, Michael Schultz, Hartmut Fricke, Andrew Cook	Development of Stochastic Delay Cost Functions	Proceedings of the 10th SESAR Innovation Days	2020 / green
https://westminsterresearch.westminster.ac.uk/item/v28q8/development-of-stochastic-delay-cost-functions				
CF	David Mocholí González, Rubén Alcolea Arias, Ricardo Herranz	Evaluation of Flight Prioritization Mechanisms Through Agent-Based Modelling	Proceedings of the 10th SESAR Innovation Days	2020 / green
https://www.sesarju.eu/sites/default/files/documents/sid/2020/papers/SIDs_2020_paper_61red.pdf				
PhD	Eduardo Andres, Daniel Gonzalez-Arribas, Manuel Sanjurjo-Rivo, Manuel Soler, Maryam Kamgarpour	GPU-Accelerated RRT for Flight Planning Considering Ensemble Forecasting of Thunderstorms	Proceedings of the 10th SESAR Innovation Days	2020 / green
https://uc3m-phd-aerospace.es/publications-2020/				

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PhD student / CF project	Authors	Title	Title of the journal / proceedings / book	Year / open access
PhD	Billy Josefsson, Anastasia Lemetti, Tatiana Polishchuk, Valentin Polishchuk, Christiane Schmidt	Integrating Weather Impact in RTC Staff Scheduling	Proceedings of the 10th SESAR Innovation Days	2020 / green
https://weber.itn.liu.se/~tatpo46/pps/SIDs2020_WL.pdf				
PhD	Manuel Mateos, Ignacio Martín, Pedro García, Rubén Alcolea, Ricardo Herranz, Oliva G Cantú-Ros, Xavier Prats	Predicting requested flight levels with machine learning	Proceedings of the 10th SESAR Innovation Days	2020 / green
http://hdl.handle.net/2117/341211				
PhD	Homeyra Khaledian, Xavier Prats, Jordi Vila-Valls	Real-time Identification of High-Lift Devices Deployment in Aircraft Descents - An Interacting Multiple Model Filtering Application Validated with Simulated Trajectories	Proceedings of the 10th SESAR Innovation Days	2020 / green
http://hdl.handle.net/2117/337090				
CF	José Manuel Cordero, Iciar García-Oviés, Enrique Iglesias, Carlo Abate, Simone Pozzi, Carlo Dambra, Irene Buselli, Luca Oneto, Alvaro Rodriguez-Sanz	Traffic Characterization for a Dynamic and Adaptive Trajectory Prediction Data-Driven Approach	Proceedings of the 10th SESAR Innovation Days	2020 / green
https://www.sesarju.eu/sites/default/files/documents/sid/2020/papers/SIDs_2020_paper_54red.pdf				
CF	Hugues Brenot, Nicolas Theys, Christophe Lerot, Jeroen van Gent, Michel Van Roozendael, Scott Wilson, Rory Clarkson, Lieven Clarisse, Dave M Hyman, Michael J Pavolonis, Riccardo Biondi, Pierre-Yves Tournigand, Stefano Corradini, Giuseppe Salerno, Adam Durant, Daniel Bannister, Klaus Sievers	Volcanic SO_2 Height SWIM Service	Proceedings of the 10th SESAR Innovation Days	2020 / green
https://www.sesarju.eu/sites/default/files/documents/sid/2020/papers/SIDs_2020_paper_72red.pdf				
CF	Yixing Luo, Yijun Yu, Zhi Jin, Yao Li, Zuohua Ding, Yuan Zhou, Yang Liu	Privacy-Aware UAV Flights through Self-Configuring Motion Planning	Proceedings of the 2020 IEEE International Conference on Robotics and Automation	2020 / green
https://oro.open.ac.uk/69154/				
CF	Jeroen van Gent, Hugues Brenot, Nicolas Theys, Lieven Clarisse, Scott Wilson, Rory Clarkson, Michel Van Roozendael	Prototyping of a multi-hazard early warning system for aviation and development of NRT alert products within the EUNADICS-AV and OPAS projects	Proceedings of the 2020 IEEE International Geoscience and Remote Sensing Symposium	2020 / green

PhD student / CF project	Authors	Title	Title of the journal / proceedings / book	Year / open access
http://sacs.aeronomie.be/OPAS/20200930_IGARSS_proceedings_vanGent_OPAS.pdf				
PhD	Sashiko Shirai Reyna, Miguel Mujica Mota, Daniel Delahaye, José Maria Ortiz	Improvement of APOC Operations by using Simulation and Experimental Economics: Conceptual Approach	Proceedings of the 32nd European Modeling & Simulation Symposium	2020 / green
https://hal-enac.archives-ouvertes.fr/hal-03094829				
PhD	Homeyra Khaledian, Jordi Vila-Valls, Eric Chaumette, Xavier Prats	On Parametric Model Mismatch in Nonlinear EKF Approximations	Proceedings of the 54th Asilomar Conference on Signals, Systems, and Computers	2020 / green
http://hdl.handle.net/2117/341216				
PhD	Homeyra Khaledian, Xavier Prats, Jordi Vila-Valls	Advanced Statistical Signal Processing for Next Generation Trajectory Prediction	Proceedings of the 9th International Conference for Research in Air Transportation	2020 / green
http://hdl.handle.net/2117/328697				
PhD	Jonas Ernst Bernhard Langner, Thomas Feuerle, Garoe Gonzalez	Decision Support System for Airline Operation Control Hub Centre (DiSpAtCH) - Initial research results and developed framework	Proceedings of the 9th International Conference for Research in Air Transportation	2020 / green
https://drive.google.com/file/d/1uW-tUmcMYUW7zf9OANH-TJQkBMJGoDFe/view				
PhD	Manuel Mateos, Ignacio Martín, Pedro García, Ricardo Herranz, Oliva García Cantú-Ros, Xavier Prats	Full-scale pre-tactical route prediction: machine learning to increase pre-tactical demand forecast accuracy	Proceedings of the 9th International Conference for Research in Air Transportation	2020 / green
http://hdl.handle.net/2117/345147				
PhD	Anastasia Lemetti, Tatiana Polishchuk, Valentin Polishchuk, Raúl Sáez, Xavier Prats	Identification of Significant Impact Factors on Arrival Flight Efficiency within TMA	Proceedings of the 9th International Conference for Research in Air Transportation	2020 / green
https://drive.google.com/file/d/1tYS20MsZM1CGiz0XD4EtQddHc02WH2QS/view				
PhD	Sashiko Shirai Reyna, Miguel Mujica Mota, Daniel Delahaye, José M Ortiz	Modelling and Simulation of APOC Operations	Proceedings of the 9th International Conference for Research in Air Transportation	2020 / green
https://research.hva.nl/en/activities/modelling-and-simulation-of-apoc-operations				
PhD	Henrik Hardell, Vishwanath Bulusu, Anastasia Lemetti, Tatiana Polishchuk, Valentin Polishchuk, Enric Royo	Morphing STARs vs drones and weather in TMA	Proceedings of the 9th International Conference for Research in Air Transportation	2020 / green
https://drive.google.com/file/d/1bb3Z6WfqTdVz2MnFZDn5-2iQi29ungid/view				
CF	Emmanuel Sunil, Ralph Koerse, Stijn van Selling, Jan-Willem van Doorn, Thomas Brinkman, Junzi Sun	METSIS: Hyperlocal Wind Nowcasting for U-space	Proceedings of the 11th SESAR Innovation Days	2021 / green

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PhD student / CF project	Authors	Title	Title of the journal / proceedings / book	Year / open access
https://www.sesarju.eu/sites/default/files/documents/sid/2021/papers/SIDs_2021_paper_88.pdf				
PhD	Manuel Mateos, Ignacio Martín, Rubén Alcolea, Ricardo Herranz, Oliva G Cantú-Ros, Xavier Prats	Unveiling airline preferences for pre-tactical route forecast through machine learning. An innovative system for ATFCM pre-tactical planning support	Proceedings of the 11th SESAR Innovation Days	2021 / green
http://hdl.handle.net/2117/359053				
PhD	Raúl Sáez, Homeyra Khaledian, Xavier Prats, Andréas Guitart, Daniel Delahaye, Eric Feron	A fast and flexible emergency trajectory generator	Proceedings of the 14th USA/Europe Air Traffic Management Research and Development Seminar	2021 / green
https://hal-enac.archives-ouvertes.fr/hal-03351220				
CF	David Mocholí González, Rubén Alcolea Arias, Ricardo Herranz	Exploring future UDPP concepts through computational behavioural economics	Proceedings of the 14th USA/Europe Air Traffic Management Research and Development Seminar	2021 / green
https://drive.google.com/file/d/1pI3JYvQvCgaBRa-d17YB15Tn9Sm3oHN3/view				
PhD	Jan Evler, Michael Schultz, Hartmut Fricke	Flight prioritization and turnaround recovery	Proceedings of the 14th USA/Europe Air Traffic Management Research and Development Seminar	2021 / green
https://drive.google.com/file/d/1GNQ5MK3jO7hw5fpu1UyPFMM9lTi92XN8/view				
PhD	Ralvi Isufaj, David Aranega Sebastia, Miquel Angel Piera	Towards conflict resolution with deep multi-agent reinforcement learning	Proceedings of the 14th USA/Europe Air Traffic Management Research and Development Seminar	2021 / green
https://drive.google.com/file/d/1-dpSGiqEjiXXix5fGWLrabT8FrWhIs4h/view				
PhD	Jan Evler, Judith Rosenow, Hartmut Fricke	Airline Schedule Recovery at Hub Airports including Dynamic Cost Indexing and Re-Routing	Proceedings of the 10th International Conference for Research in Air Transportation	2022 / green
https://drive.google.com/file/d/1ps5BwJqJptCx-468eDhpFU7u3IRXilXK/view				
PhD	Ilir Kola, Ralvi Isufaj, Catholijn M. Jonker	Does Personalization Help? Predicting How Social Situations Affect Personal Values	Proceedings of the 1st International Conference on Hybrid Human-Artificial Intelligence	2022 / green
https://www.hhai-conference.org/wp-content/uploads/2022/06/hhai-2022_paper_51.pdf				

Gap analysis

As the final result of the gap analysis, a semantic similarity index was obtained for each of the projects being analysed with respect to the descriptions of the nine SRIA flagship activities, and the least overall connected to the SRIA are ranked in Table 20 (Appendix B), with the top three shown in Table 12. The first column is the ranked weakest link (i.e. least-connected first), although undue importance should not be ascribed to differences between specific rankings. As a further, crude validation exercise, three keywords were manually assigned to each of the projects, and searched in the SRIA, to check that none of the projects had an apparently very strong representation in the latter. In most (14) of the cases (projects), the total (of three) keyword hits was zero or one. The highest, rather counter to the ranking,

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was the occurrence of "training" (indicated by project 1), 14 times in the SRIA. The text samples (right-hand column) were normally taken from the projects' final reports and are unedited. For further information on them, the reader is referred to the Engage research repository [60].

Table 12: Top three projects least connected with the SRIA

Project / rank	WBS	Acronym	Title	Text samples
1	16.04	-	Human Performance Management System R&D	Project 16.04 was concerned with the overall management and coordination of the 16.04.0x projects that were responsible for the SESAR ATM Human Performance Management System R&D activities. This R&D covered four areas: • 16.04.01 Evolution from ATM HF Case to a HP Case Methodology for SESAR • 16.04.02 HP Tool Repository of SESAR Standard HP Methods and Tools • 16.04.03 Impacts of Future Systems and Procedures on Selection, Training, Competence and Staffing Requirements • 16.04.04 Social and Cultural Factors impacting on SESAR Changes All these projects have now completed and have delivered their final deliverables. As explained in section 3.8 of the ATM Master Plan (Edn 2), the human element remains pivotal to the success of SESAR, and also that the concepts being developed within SESAR must take account of human strengths and weaknesses in their development. The deliverables of the 16.04.0x projects provide the guidance necessary for SESAR R&D projects to take account of the human aspects when developing SESAR concepts, and therefore these deliverables are essential to facilitating the ultimate deployment of the ATM master plan roadmap.

2	16.01.03	-	Develop techniques for Dynamic Risk Modelling	The objectives and achievements of the project are summarized as follows:
				• Demonstrate the added value of DRM with respect to static risk modelling
				  ○ Achieved and documented in Deliverable "D09" Dynamic Risk Modelling SESAR test case application and lessons learned. This comprehensive report includes all steps and results of DRM application. Agent-based DRM has been shown to be workable and useful for ATM applications.
				• Produce a guideline for *when* and *how* to apply DRM techniques in real world analysis
				  ○ Achieved and document. through iterative approach from initial guidelines until final The result was coordinated with P16.06.01 that addresses the SESAR Safety Reference Material and its application.

3	12.07.03	-	Airport Performance Assessment and Management Support Systems	The main objective of the Primary Project "Airport Performance Management Assessment and Management Support Systems" (APAMS) was to specify, develop and verify the AirPort Operation Centre (APOC) support tool, which is able to collect and evaluate information from the Airport Operations Plan (AOP), allowing monitoring and management of the airport´s performance by providing mechanisms to the APOC stakeholders to resolve any unexpected operational disruptions in a collaborative manner.

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To avoid overly cumbersome referencing, and to improve readability, the projects (listed in Table 20) are referred to by the rank numbers in the first column, and various abbreviations thereof.

The assumption of this analysis is that the weakly linked past projects might point to blind spots in a work programme largely based on the SRIA. For such blind spots to be worthy of further investigation those weakly linked projects should have been successful and left sufficient questions for further research open. Or, such projects had not been successful, but their original question is still valid and alternative approaches are conceivable.

As shown in Table 20, it is striking that the two weakest linked past projects are safety-related. This begs the question whether the SRIA is sufficiently safety-oriented, given the undisputed mantra in the aviation world that safety is first and foremost. The SRIA has not allocated safety as an area of work in the portfolio but rather as a horizontal performance criteria for all work areas, thereby forcing safety work to be undertaken in each area. Whilst this might be a good approach, the contributions of the nine flagship activities to the safety dimension is quite modest (four report at best “maintaining” safety; two mention “maintained if not improved”; one does not report; and only two mention possible improvements). Clearly, this falls significantly short of earlier ACARE/SES objectives of a ten-fold safety improvement. **An additional focus on safety is more than justified**.

Attention on modelling and measuring seems to be a more pragmatic approach than further methodological developments, often running ahead of their validation and use. Therefore, continued work on project 2, **developing techniques for dynamic risk modelling**, is supported, and project 1, the R&D human performance management system, should be analysed as to its practical impact so far, before a selective follow-up could be recommended. One should treat project 11, on further evolution of human factors, equally sceptically, as its final report calls once again for further guidance material and process development, while at the same time only (vaguely) mentioning a couple of initial use cases.

Continuing down the list in Table 20, it is even more striking that out of the next eight in the top ten weakest linked projects, seven relate to airport developments. Looking at the content of the SRIA, airports only receive a notable mention in two areas: “connected and automated ATM” and “multimodal and passenger experience”. After many years (decades) of strategies to extend ATM towards airports (recall the gate-to-gate strategy, the airport observatory initiative, and the more recent focus on integrating network and airport planning), the current SRIA seems to attach much less importance to the role of airports, with only sparsely identified work items (queuing management, runway optimisation and automation; drone integration into low-level airport airspace; environmentally optimised taxiing, climb and descent; multimodal integration). This may be related to the SESAR focus more specifically on airports from the ATM-impacting perspective.

Looking at those seven past projects, one cannot avoid noting the high level of maturity for: project 3 on airport performance assessment; project 4 on integration of A/S/D/MAN into CDM; project 6 on integrating various decision tools at the APOC level; project 7 on specifications for the tower position; and, project 9 on enhanced surface safety nets – the large majority of these ended at TRL6 with only a handful ending at TRL5. In fact, one can conclude similarly for project 12, on the integration of CDM in SWIM. It is therefore unlikely that further upstream research in these areas is going to open up additional benefits, maybe with the exception of two specific work items focusing on **vehicle driver guidance and airport DCB**, remaining at V2 in project 10. Also, some selected work items from project 15 on **enhanced surface guidance** might deserve further work as they ended only at TRL4. Generally, project 15 was the least mature in the airport domain.

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Further work on project 5, on the prototyping of runway management tools, lends itself very well to ML approaches and seems adequately covered in the plethora of research papers on ML emerging recently. In conclusion, although the SRIA seems to downgrade the importance to airports, it may be caused by a lack of obvious avenues to explore for future **performance improvements**. We would recommend a strong focus on **ideation and Exploratory Research in the airports domain** to rebuild a dedicated work programme in the medium term.

For several more past projects in the twenty listed as most weakly linked to the SRIA, the maturity argument weighs even more heavily. One could almost ask why these had not already been more firmly established in the demonstration stage (see project 14 on approach with vertical guidance), and directly considered ready for industrialisation (see project 19 on aeronautical databases). Project 16, on synchronised implementation of RNP, was already a demonstration and no longer considered a research project. Clearly, these are not rich sources for potential future research questions.

With a view to project 8, i.e. WBS 09.05, 'ASAS – ASPA', we suggest that ASAS and time-based spacing has received significant attention and funding over the past decades and has matured to an on-board system that has successfully been installed (and flown) on commercial aircraft by Airbus. Likewise, cockpit displays of traffic information and pilot situational awareness-enhancing displays have been developed and matured to TRL4. For both, on-board TBS (time-based separation) systems and pilot SA-enhancing displays, the achieved levels of technology readiness mean that further, lower-TRL research is not recommended. However, the question of **market-uptake, incentives to airspace users** (see also Section 2.2.4 of the SRIA [119]) and network-wide performance assessment as a function of system configuration and equipage levels presents a potentially interesting field for research. How can airspace-users be incentivised to install and use airborne TBS-technology? How can costs and benefits of installing TBS systems be aligned in an equitable fashion? Which safety and efficiency gains can be expected at different equipage levels, both individually and network-wide? These questions require a different approach than previous ASAS research, one that may involve **economic research and market mechanisms as well as network-level performance simulations**.

Concerning project 17, i.e. 'Complexity Assessment and Resolution' (WBS 10.08.01), it can be observed that research on traffic complexity as a cause of controller workload – and hence a factor constraining sector capacity – has been performed for a number of decades. One strand of research has focused on which factors contribute to traffic complexity beyond the simple traffic count and how they can be combined in an algorithm to compute a single measure. The Dynamic Density Index was proposed by NASA and is a de facto standard; other measures have been and continue to be proposed (including in Engage catalyst fund project work). However, for different look-ahead times, different factors become relevant: due to the inherent uncertainty in trajectory prediction, factors such as the number of climbing and descending aircraft, or aircraft in physical proximity, used in real-time, become meaningless with a look-ahead time of 30-90 minutes. Further research, aiming only at improving such 'analytical' indicators, used as a proxy for controller workload/sector capacity, probably should not have a high priority, but there could be value to aim at assessing the potential benefits of the use of advanced AI/ML-based techniques to predict loads and propose sector configurations.

Past research also includes the display and usage of traffic complexity indicators at the traffic manager's working position to adapt sector configuration and staffing levels accordingly. These have been developed to some maturity and recently been installed in operational en-route control centres, such as the Maastricht Upper Area Control Centre. Since these tools have all been developed to TRL6 in SESAR, further research does not appear justified.

The introduction of the User-Driven Prioritization Process (WBS 12.06.08 – Introduction of UDPP and collaborative departure sequence; project 18) has primarily focused on slot swapping within airlines, thus avoiding that the application of UDPP by one airline impacts the operations of others. A logical extension of this concept, yet to date not matured to operational implementation, is inter-airline flight prioritisation, i.e. the exchange of slots between airlines. This raises a number of questions, not all of which have yet been addressed or resolved by research:

- Whilst different market mechanisms for inter-airline flight prioritisation are currently being studied, it is not yet clear which (combination) of these is preferable, as well as practically feasible. Concerns include the commercial sensitivity of the information underlying the flight prioritisation decisions, and, consequently, the reluctance of airlines and other stakeholders to share them openly. Current research is exploring the use of privacy-preserving techniques such as multi-party computation, and this may well need continued support along the TRL pipeline.
- The network-wide effect of different market mechanisms for inter-airline flight prioritisation (as well as UDPP implementation rates at airports) should be further studied in simulation exercises. This would allow the assessing of local cf. network-wide impacts on capacity, delay, costs and other performance indicators. In addition, it might be worth studying whether UDPP (or similar) as a process for allocating scarce resources can be applied to something other than ATFM slots.
- Additional areas include the coordination of arrivals and departures in flight prioritisation, and the extension of UDPP/flight prioritisation to the execution phase, i.e. when flights are airborne.
- The extension of the UDPP concept to cover en-route resources, though conceivable, presently meets with limited enthusiasm by operational stakeholders, who argue that existing mechanisms of demand-capacity balancing appear more adequate in this flight phase.

Thus, **multiple components of extended UDPP research** suggest themselves, and it is recommended that the extent to which the above are sufficiently matured in on-going ER4 research is closely monitored as targets for important follow-up work. Specifically regarding equity and fairness in flight prioritisation, it is noted that:

- The benefits of applying inter-airline flight prioritisation should benefit all airspace users alike; this requires an agreed understanding and definition of what equity and fairness mean for all involved actors. Equity and fairness can henceforth be studied as a performance indicator. An additional challenge comprises the defining of equity/fairness across different stakeholder groups.
- Whilst inter-airline flight prioritisation will remain voluntary, i.e. no airline is forced to trade slots if the net benefit is not positive, it may well be that certain types of operation or stakeholders systematically benefit less from this mechanism than others. Whilst equity/fairness can be established as a constraint, this may lead to a suboptimal solution from a local or network-level perspective, raising the question of how optimality and equity/fairness should be traded-off.

Regarding the self-referencing entry 13 (the Engage KTN), whilst the SRIA does state that “[t]he vision, objective and expected impact of the SRIA can only be achieved by coordination with all stakeholders that develop, supply, operate, use and regulate the Integrated ATM services and infrastructure supporting aviation in Europe, covering all technology readiness levels ...” and refers to “knowledge and innovation communities” in the context of urban mobility and the impact of drones/UAVs on urban citizens, plus the need to support positive climate action, it does not cite the need for a follow-

up network to succeed the SESAR 2020 KTN, Engage, hence this correct identification in Table 12. A future KTN is, however, covered in some detail in the SESAR multiannual work programme [120].

Challenges in obtaining project deliverables swiftly has meant that there were currently some inevitable gaps in the data-driven analysis above, due to the incomplete set of outputs directly available as inputs into the process. To the best extent possible, this has been overcome by the utilisation of experts in the Engage consortium, with domain knowledge, to produce these commentaries. They are, of course, open to future updates.

To conclude the gap analysis and the SRIA, the key component research ideas for the gap analysis pillar are summarised as various research 'threads' in Table 13. In each case, a judgement was made as to the best alignment with SRIA flagship activities, and some commentary is presented on the key relationships between the Engage thread and the corresponding SRIA flagship(s). Text in black relates to the Engage thread (with the corresponding names in bold); text in light blue relates to the SRIA flagship(s) (names likewise in bold). The table is intended to initially point the reader to some main points of association and complementarity between the research directions highlighted by the Engage thread and one or two key flagships in the SRIA, as a starting point for further engagement.

Table 13: Research threads for the gap analysis pillar and relationships with SRIA flagships

Thread	SRIA flagship(s)	Summary
1		**Additional focus on safety performance:** In the analyses presented on the semantic similarity index for each of the projects in our database with respect to the descriptions of the nine SRIA flagship activities, it is noteworthy that the two weakest-linked past projects are safety related. This raised the question regarding the extent to which the SRIA is sufficiently safety oriented, given the clearly accepted view of the priority of this operational performance criterion.
	1 	**Connected and automated ATM**: The SRIA has not allocated safety as an area of specific work *per se*, but rather as a horizontal performance criterion forcing safety evaluations to be undertaken in each area. However, the foreseen contributions of the nine flagship activities to the safety dimension seem to be quite modest, from "maintaining" to "maintained if not improved", falling rather short, it seems, of earlier ACARE/SES objectives of a ten-fold safety improvement. This flagship (connected and automated ATM) aims at higher levels of automation and specific tools for safety improvement in higher levels of automation. It would be of value to stress even more the need for a well-designed and executed safety assessment, as that is usually the stepping stone for faster development and deployment, especially for safety-critical innovations. Approaches to safety assessment developed since SESAR 1 could add value here.
2		**Developing techniques for dynamic risk modelling:** The analyses presented here flagged that modelling in some projects often ran ahead of corresponding validation and use. Therefore, developing techniques for dynamic risk modelling was supported, with, *inter alia*, a suggestion that R&D relating to human performance management systems should be analysed further before selective follow-up could be recommended.

Thread	SRIA flagship(s)	Summary
	1, 2 	**Connected and automated ATM; Air-ground integration and autonomy:** These two flagships propose research into safety-critical areas, which require rigorous safety assessments. It would be of value to stress the need for well-designed and executed safety assessments for research performed in these flagships (also for other flagships, but the link to these two is more critical). However, it is readily acknowledged that material on the application of dynamic risk modelling is included in the *Guidance to Apply SESAR Safety Reference Material*, whereas it would be endorsed that actual safety assessments should deploy tools specific to the safety requirements in question.
3		**Enhanced surface/vehicle driver guidance and airport DCB:** One of the striking findings of the gap analysis was that out of the eight projects in the top ten weakest linked projects, seven related to airport developments. This particular topic would benefit from further development as it did not reach TRL 6 in all aspects (with some SESAR Solution exceptions).
	1 	**Connected and automated ATM:** The SRIA formulation addresses airports in two areas: "connected and automated ATM" and "multimodal and passenger experience". Enhanced surface/vehicle driver guidance and airport DCB might further be developed particularly under the high-level R&I need/challenge of "Airport automation including runway and surface movement assistance for more predictable ground operations" outlined within the former flagship.
4		**Ideation and ER in airports (performance) domain:** This particular area seems to be weakly linked, while recent years saw various strategies to extend ATM towards airports (recall the gate-to-gate strategy, the airport observatory initiative, and the more recent focus on integrating network and airport planning). A strong focus on ideation and Exploratory Research in the airports domain is recommended to rebuild a dedicated work programme in the medium term.
	8 	**Artificial intelligence (AI) for aviation**: Whilst the SRIA seems to attach rather less importance to the role of airports in this flagship, some of the airport-related work lends itself very well to ML approaches. The topic covering the airports (performance) domain is not necessarily linked to AI, but many applications, especially digitalisation, can be achieved using AI and ML techniques to build innovative and more advanced performance frameworks.
5		**Market-uptake and incentivising airspace users, with performance simulations:** This thread addressed, *inter alia*, incentivisation for the use of TBS (time-based separation) technology, raising questions on market uptake, incentives to airspace users and network-wide performance assessment as a function of system configuration and equipage levels. How can the costs and benefits of installing TBS systems be aligned in an equitable fashion? Which safety and efficiency gains can be expected at different equipage levels, both individually and network-wide?
	2 	**Air-ground integration and autonomy:** Market-uptake and incentivising airspace users, for example for TBS (time-based separation) systems could loosely fit in the flagship on air-ground integration and autonomy, developing further the assessments needed for TBS (or other similar) business cases. Such research requires deeper economic and market mechanisms investigations, as well as network-level performance simulations.
6		**Advanced AI/ML to predict loads and propose sector configurations:** Further research, aiming only at improving 'analytical' indicators, used as a proxy for controller workload/sector capacity, probably should not have a high priority, but there could be value to aim at assessing the potential benefits of the use of advanced AI/ML-based techniques to predict loads and propose sector configurations.

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Thread	SRIA flagship(s)	Summary
	8 	**Artificial intelligence (AI) for aviation**: Research into advanced AI/ML techniques to predict sector loads and propose sector configurations would seem to be potentially accommodated in the capacity-on-demand and dynamic airspace flagship, but would in fact most likely fit better in the artificial intelligence (AI) for aviation flagship if the goal were to be to develop and use advanced AI/ML-based techniques predicatively.
7		**Extended UDPP research** *(multiple components):* A logical extension of this concept, to date not matured to operational implementation, is inter-airline flight prioritisation, i.e. the exchange of slots between airlines. The concept should benefit all airspace users alike. This requires an agreed understanding and definition of what equity and fairness mean for all involved actors. This further raises the question of how optimality and equity/fairness should be traded-off.
	3 	**Capacity-on-demand and dynamic airspace:** UDPP research is contained within this flagship, aiming at extending the concept, but not mentioning explicitly inter-airline slot swaps or specific indicators to explore. Definitions of equity and fairness across all stakeholders, and analyses of the corresponding trade-offs, would clearly bring important added value to the research in this flagship.

'Horizon' flagships

The six horizon flagship activities proposed for seeding the ATM concepts roadmap (see right hand side of Figure 6) are presented in the following sub-sections, in no implied order of priority.

Quantum computing

Quantum computers use quantum physics properties to enable certain types of computations to be performed vastly quicker than classical computers. Approximately fifty countries are currently engaged in national and (especially) international quantum research and development projects, with private capital investment and multidisciplinary cooperation being prevalent.

The most widely used model deploys a basic unit of memory known as a 'quantum bit' or 'qubit'. A fundamental advantage of quantum computers is the ability to consider large numbers of combinations simultaneously. Although any computation that can be solved by a classical computer could also be solved by a quantum computer, the former are still likely to outperform quantum computers in some situations. Further work is needed on specifying the real-word value of quantum computing and developing appropriate benchmarks and metrics to support this. Also, whilst in 2019 Google AI and NASA claimed to have performed a 'quantum computation' that would not have been possible on any classical computer, there are still stability issues for quantum computers that need to be resolved. Quantum computing could expose cybersecurity vulnerabilities, through solving integer factorisation problems, which underpin many public key cryptographic systems, including blockchain applications, thus already generating improved cybersecurity research and attracting governmental interest in secure quantum communications, quantum-enabled (internet) networks and quantum-proof cryptography. Such issues are clearly important in the ATM context regarding not only CNS, but also in the context wider of information exchange over networks, supporting SWIM and privileged data exchange (e.g. for UDPP), and in detecting fraudulent and malevolent interventions.

Quantum computing is likely to bring particular opportunities for simulation, especially when coupled with machine learning and AI. These are expected to include higher-precision weather forecasting and

improved (in detail, lookahead and scope) environmental impact models, for example. Applications involving very much faster (and some currently infeasible) solutions to search space and combinatorial problems, may offer vastly improved capabilities both for operational/tactical searches of improved solutions to complex capacity constraints in ATM. In the SESAR exploratory research context, in particular, much larger numbers of future scenario simulations and hitherto infeasibly complex models are likely to be enabled to be run.

Linked to the vast increase in the capability to search parameter spaces, quantum computing may also help to validate procedures and systems, in particular from a safety perspective. The more systematic exploration of operating points will lead to higher levels of confidence in system behaviour, especially when stochastic processes are involved. Indeed, quantum algorithms are naturally well fitted to solve probabilistic problems, and classical computation of these models can be viewed as an emulation of quantum algorithms for deterministic machines.

Strong AI

Strong AI is also known as general AI or artificial general intelligence. It usually refers to a currently theoretical form of AI whereby a computer will have an intelligence comparable to that of humans, with the ability to solve problems, learn, and plan future contingencies. Current forms of AI, and ML algorithms, are dependent on (often biased) training data used as inputs, to the extent that truly predictive capabilities have not currently been developed (one has to wait for a particular type of event to occur and then re-train the model). Whilst some argue that strong AI is not achievable, others, such as DeepMind, argue that reinforcement learning (which comprises an environment, agents, and rewards) is a sufficient basis for strong AI, and see as key the inclusion of agents that learn through interaction with the environment, which could be through operational sensors. Such tools, even if not attaining the full specification of strong AI (however that may be defined), may bring greatly superior capabilities to ATM both through improved forecasts and predictive capabilities, strategically and tactically, and also underpinning stronger metamodels for performance assessment and with 'strong emergence' foresight capabilities, including improved human behavioural models, e.g. for future policy generation, whereby a host of new possibilities may well be proposed through vastly increased modelling power and utility.

Taking a specific application area, the Alan Turing Institute explains[4] the concept of "digital twins" – computational representations of aeronautical assets, which can be used to model, optimise and predict the performance of assets such as aircraft engines, wings and even drones. This leverages existing sensor network data from engines and other aircraft components. Instead of treating sensors and their data in isolation, a more holistic approach, deploying a unified, instrumentation-based model, can be used for better risk mitigation, diagnosis, performance assessment and forecasting. Machine learning tools and AI may be paired with data from the sensors to 'fill in the blanks' (since sensors in aeronautics are often somewhat sparse). The coupling of advanced sensor technologies with ML/AI techniques, might well also support system development in other contexts, such as integrating the connected passenger through multimodal itineraries and multiple systems and processes at the airport. With greater computational power and more advanced machine learning and AI development, through deep neural networks, more powerful dimension reduction and polynomial classification, this approach could be extended more widely to larger systems, and help to build better predictive models

[4] https://www.turing.ac.uk/research/research-projects/digital-twins-aeronautics

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of not only specific aircraft and component safety profiles, but of the ATM network and broader socio-technical system, contributing to models even at the design stage.

From a socio-economic point of view, strong AI may be highly valuable in more efficiently allocating resources, also having an impact on the workforce. AI may take more responsibility, as opposed to a more classical advisory position, automatically allocating (human) resources. It may also change the nature of the workforce in various industries, since it will take up some roles now assumed by humans, but it will likely continue to require human monitoring in many such contexts.

Integrated ticketing and virtual interlining

Europe is not alone in being caught in a fragmented modal service culture. Nevertheless, a comprehensive review of existing single-ticketing solutions and identification of the benefits, barriers and lessons learned is needed. Single ticketing and virtual interlining already exist in various formats, such as specific rail-air collaborations (Lufthansa, Deutsche Bahn) and much wider schemes (AccesRail[5] is an example of an IATA Travel Partner).

An examination of existing virtual interlining models (intermodal and air-only) and online travel agencies (OTAs) would give better insights into the implications for airspace users, airport infrastructure requirements and other modal travel service providers (e.g. rail). Particular challenges needing investigation relate to overcoming barriers in changing and harmonising regulations across modes (currently considered to be too problematic), accountability (particularly during disruption and with limited capacities driven by high load factors), revenue sharing and the management and insurance of new business models, including the facilitation of new market entrants (i.e. maintaining appropriate open competition). Operationally, the impacts on holding flights for delayed trains, and vice versa, could be significant – further metric development and scenario simulations are required here.

Overcoming the regulatory, accountability, revenue sharing, and insurance barriers would open up the opportunities for new businesses, offering real Mobility as a Service (MaaS), not just 'ticketing as an app' approach, as currently available (e.g. giving information on traffic jams, delays, cancellations, and enabling the booking of a train or bus ticket to the airport).

Travel operators may be envisaged that sell seats offered by transport operators of all modes, for a certain level of service, building on more limited integration currently in place (e.g. with certain guarantees when connecting across different low-cost carriers at an airport, or joint air-rail tickets). These could act as the travel organisers, also covering needs in case of disruption, throughout the booked travel in a door-to-door context and based on the chosen service level and priorities (e.g. cost, flexibility, environmental impact). It would be interesting to explore passenger expectations and willingness to pay for such integrated services.

European risk register for ATM and air transport resilience

"Resilience" is mentioned often in the SRIA, mostly with reference to cybersecurity, but also flagging climate/meteorological resilience and passenger journey resilience. However, the need may be suggested for a higher-level, European risk register for ATM and air transport, taking account of space

[5] https://accesrail.com/

weather, pandemics and more disperse ATM service outages (by whichever means, e.g., climate, higher levels of automation, cyber attacks, etc.), and also potentially broader adversarial attacks aimed at destabilisation. This should also include potential degradation of energy supply in the air transport chain, as a result of the situation in Ukraine.

We already have the European Aviation Crisis Coordination Cell (EACCC), with the role of supporting coordination of the response to network crisis situations impacting adversely on aviation, in close cooperation with corresponding structures in the member states. A broader example of the latter is the UK National Risk Register ("The 2020 National Risk Register provides an updated government assessment of the likelihood and potential impact of a range of different malicious and non-malicious national security risks (including natural hazards, industrial accidents, malicious attacks, and others) that may directly affect the UK and its interests over the next two years"[6]).

Learning from the past experience of the EACCC could indicate which type of risks to include in the register, how to best use it, to monitor the emerging strategic and (pre-)tactical situations, and being overall proactive in calling up the crisis cell and/or other stakeholders and units.

Complexity science and complex network theory have already proven in ATM to be well-suited tools with a range of metrics particularly adept at measuring network resilience, and these could be brought to bear to assess the absorptive, adaptative and restorative forms of resilience currently in place, to identify key vulnerabilities and develop cost-benefit trade-offs for mitigations. Further, development and use of novel techniques based on machine learning to support risk (any risk from the register) intelligence services in aviation/ATM could be encouraged, to support network resilience.

Regarding such resilience, it would also be informative to explore what lessons have been learned from the Covid-19 pandemic, for example, in terms of the sustainability of current financial, business and performance assessment models for airspace users and ANSPs.

Improved route emissions metrics and policies

The need to cut back on aviation's climate impact is generally accepted and emissions capping and a Trading System[7] have been put in place in Europe (focusing on CO_2 emissions in aviation). However, environmental impacts are manifold and difficult to model, and more importantly monitor, beyond simple CO_2 emissions. Non-CO_2 emissions are responsible for roughly 75% of aviation's global net effective radiative forcing. Among them, NO_x emissions depend on pressure ratios and the combustion temperatures of jet engines, so that more efficient engines ironically may lead to greater NO_x emissions. The climate impact of NO_x emissions and contrails depend on many factors, including flight level, atmospheric conditions, time of day and year, and geographic latitude, and is to date not perfectly well understood. Contrail-optimised flight routes may hence increase the fuel burn and hence also CO_2 emissions, leading to the necessity to trade-off various climate impacts. Sustainable aviation fuels (SAFs) may mitigate some of these climate impacts, but SAFs are not presently available in sufficient quantity and their total life-cycle climate impact needs to be considered.

[6] https://www.gov.uk/government/publications/national-risk-register-2020

[7] https://ec.europa.eu/clima/eu-action/eu-emissions-trading-system-eu-ets_en

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Airlines as the major civil airspace user are primarily orientated towards profit maximisation and customer satisfaction, and environmental considerations are of secondary importance, unless they are well aligned with cost savings or customer retention. The objective of saving aviation fuel burn (i.e. CO_2 emissions) is generally well aligned with the cost saving objective but environmentally friendly (e.g. contrail-optimised, or NO_x-optimised) routes might well be longer, increase fuel burn, related costs and flight times.

Despite the introduction of the SES Performance and Charging Scheme[8], the present air traffic route charging system is mainly based on a cost recovery method, leading to differences in route charges. In some cases, especially when direct routes lead thorough airspace with higher route charges, the total cost of a flight, including the cost of fuel, and route charges, can be reduced by flying a longer route through cheaper airspace. Following a recent reform, now the flown rather than the filed flight plan is the basis for route charging; this is desirable from a service provider's point of view but may ironically have aggravated the problem of emissions, as longer, but overall cheaper routes result in higher emissions.

Although passengers comprise the largest stakeholder in aviation, they are not fully aware of airline operational strategies and can largely only contribute to flight sustainability through passive means, such as purchasing carbon footprint offsets. Currently, their actions do not provide a direct trigger for airlines to improve operational sustainability. Many governments are proposing or implementing flight taxes to off-set aviation's environmental impact. If implemented correctly, this could provide new possibilities for more sustainable flight operations. The challenge is to how to create a system that gives policymakers the ability to measure and monitor emissions and the possibility to propose and implement environmentally beneficial emission trading or even tax policies that fundamentally affect how airlines operate. A full cost model that establishes a realistic price for the transportation and makes the environmental impact of travelling choices more transparent to customers may influence their decisions; this could include the aspect of inter-modality, i.e. planning and executing trip planning across competing or complementary flight modes.

ATM-U-space coordination; UAM access mechanisms

U-space is a crucial building block for the successful deployment of unmanned aerial systems and urban air mobility. Since these new market entrants are presently not sufficiently covered by existing flight rules and airspace management developed to serve 'traditional' aviation, concepts have been developed and regulations drafted in the recent past. The SESAR project CORUS-XUAM is developing a concept of operations for Urban Air Mobility and demonstrating its feasibility in a series of Very Large-scale Demonstrations in a number of European countries. Despite these efforts, a number of open questions remain. ATM-U-space coordination, the structure of U-space airspace (present concepts distinguish between categories X, Y and Z) and segregation (free route airspace, layers, tunnels in the sky); the operation of vertiports; and priority rules are amongst such questions.

(a) ATM-U-space coordination

The cooperation between air traffic management and UAS management systems (or 'U-space') concerns the physical and procedural interface between both systems with a view to information flow, airspace access management and tactical control. The ATM-U-space interface becomes particularly

[8] https://webgate.ec.europa.eu/eusinglesky/node_en

relevant when admitting manned aircraft to U-space and/or UAS to controlled airspace in the future (present U-space regulations assume the presence of manned aviation in U-space and of drones in controlled airspace are exceptional and usually related to on-nominal situations. This would otherwise entail equipage requirements that are non-trivial and potentially costly. However, manned aviation, especially recreational aviation, may well be present in VLL airspace where drones are also likely to operate.) Equipage requirements, management of non-nominal/emergency situations and common services, e.g. meteorological information, need to be developed. The vicinity of airports, in which both vehicle types will operate, and a risk of airspace infringements exists, as well as urban airspace, are of particular interest. There is a strong link with the Smart City concept, under development and eagerly taken up by some European cities, which see great potential in UAM and U-space for the benefits of their citizens, although admittedly many questions remain open.

(b) Priority and market mechanisms for U-space and UAM

Different vehicles and different types of operations will exist in U-Space and especially in UAM, including police and other surveillance operations, urgent delivery of medical supplies, air taxi operations, delivery operations. Studies on societal acceptance as well as experiments with air traffic controllers, suggest a different degree of acceptance and willingness to prioritise these different operations, and this will only be aggravated when piloted flights are admitted to U-Space/UAM. Rules of the air for manned aviation, especially in VFR airspace, do not appear exhaustive to solve this question, such that new rules and criteria may need to be established. The present assumption is that more than one U-space service provider (USSP) may operate in any U-space and provide services to drone operators. Access to U-space and UAM airspace will have to be based on equipage requirements and respect principles of equity, whilst at the same time applying yet-to-be-defined priority rules, e.g. priority of emergency and security/safety-relevant flights as foreseen by current regulations (e.g. Article 4 of Implementing Regulation (EU) No 923/2012). Remaining battery charge/flight distance and the presence of passengers versus goods, or the size of vehicles and type of operations, are additional criteria that may be considered for defining priority rules. Such priority rules may be relevant for flight planning and airspace access, as well as for scheduling and demand management at vertiports (whose principles of operations are yet to be defined).

In controlled airspace, demand-capacity balancing is performed principally through the Network Manager by applying restrictions and encouraging re-routings in case demand exceeds the capacity of certain airspace elements at peak times. The use of U-space and UAM airspace through a plethora of actors with heterogenous operating patterns and vehicles, as well as the more on-demand nature of UAS traffic, as compared to scheduled flight operations, make it questionable whether such an approach is applicable to U-space and UAM. Apart from applying priority rules, and in case demand exceeds capacity of access to airspace and vertiports, one approach is to investigate whether economic approaches, such as auctioning, selective pricing or different service levels are practical, whilst at the same time attempting to maintain principles of equity, and avoiding market dominance of specific operators of types of operations.

As outlined in Section 2.2, Engage had five high level objectives. The following table summarises the key achievements of the four technically focused objectives (the other objective being primarily related to KTN management). There is some intentional duplication to aid the reader, for example deliverables which summarise the final catalyst fund project presentations are shown with the CF project achievements as well as with those of the thematic challenge workshops. Section 2.5 has further information about the listed deliverables.

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Table 14: Engage high level objectives, key achievements and corresponding public deliverables

High level objectives	Key achievements	Public deliverables
Manage the network's communication related activities, including on-line (e.g. website and social media) and organising workshops whilst supporting S3JU initiatives such as the organisation of the SIDs and coordination with the SESAR Scientific Committee.	launch of the Engage website, which received approximately 1000 hits per month over the duration of the KTN; Twitter account (850+ followers) which sent on average over 30 Tweets/retweets per month; over 50 Engage presentations given at events	• D2.1 (C&D plan) • D2.2 (C&D reporting)
	14 thematic challenge workshops were organised by the consortium which brought together ER and IR researchers; TC workshop material was published on the Engage website; 2 technical workshops were organised for Engage PhD students as an introduction to data sources and techniques for building passenger itineraries	• D2.5 (workshops 2018) • D2.6 (workshops 2019-2020) • D2.7 (workshops 2021) • D3.1 (final presentations of wave 1 catalyst fund projects) • D3.2 (final presentations of wave 2 catalyst fund projects)
	support and expertise were provided to 4 editions of the SESAR Innovation Days conference (2018-2021); this included organising and publicising the Call for papers and posters, plus leading the review and selection of submitted contributions and the preparation of the conference programme	• D2.8 (SIDs 2018) • D2.9 (SIDs 2019) • D2.10 (SIDs 2020) • D2.11 (SIDs 2021)
Build an inspiring and user-friendly ATM observatory (EngageWiki) to monitor, identify and analyse relevant new opportunities for innovative ATM research, with a repository to host tools, reports and publications and a	4 thematic challenges were central to the KTN, and were selected to address research topics which were not contemporaneously (sufficiently) addressed by the SESAR research programme; these were supported by dedicated workshops organised by the consortium (see previous objective); 2 sets of briefing notes were prepared as inputs to these workshops	• D3.4 (TC selection) • D5.6 (TC briefing notes)

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High level objectives	Key achievements	Public deliverables
roadmap of innovative and interdisciplinary ATM concepts beyond SESAR 2020.	the EngageWiki (Engage 'knowledge hub') was designed as the one-stop, go-to source for ATM research and knowledge in Europe; innovative features included an interactive research map of ATM (integrating ER and IR projects), an interactive roadmap of (future) ATM concepts, a consolidated and searchable research repository (with 1400+ reports and 650+ conference papers), a database of over 110 undergraduate and postgraduate teaching programmes, 3 complete lecture programmes, and listings of relevant jobs, internships and PhD opportunities	• D3.9 (reference document for the wiki, superseding D3.7 and D3.8 wiki reporting)
	the highlighting of future research opportunities for ATM, structured around three research pillars with SESAR's Strategic Research and Innovation Agenda used as a focal point of comparison; detailed proposals for future research, plus research enablers and platforms are suggested for SESAR 3	• D3.10 (R&I insights, superseding D3.5 and D3.6 opportunities for innovative ATM research)
Stimulate the transfer of exploratory research results towards ATM application-oriented research by identifying the maturity of research results and facilitating the link with higher-maturity research.	2 waves of catalyst funding were available to promote cooperation between industry and academia, and between exploratory research and applied research; 18 catalyst fund projects, linked to the four thematic challenges, stimulated the transfer of exploratory research results towards ATM application-oriented research, providing very high value for money; project findings were presented at the Engage TC workshops and/or the SIDs; almost 130 research outputs were produced by these projects within the Engage timeframe; note also the in-kind support given by approximately 60 industry partners	• D3.1 (final presentations of wave 1 projects) • D3.2 (final presentations of wave 2 projects) • D3.10 (CF lessons learned) • D4.1, D4.2, D4.3, D4.4, D4.5, D4.6, D4.7, D4.8, D4.9, D4.10, D4.11, D4.12, D4.13, D4.14, D4.15, D4.16, D4.17, D4.18 (each report summarises a CF project)

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High level objectives	Key achievements	Public deliverables
Support European ATM education and training in the ATM community to develop new talent with a deep knowledge of the future ATM scientific research needs; to sustain a supply of ATM research talent and to stimulate the next generation of ATM operational and engineering staff.	the Engage PhD programme financially supported and co-mentored 10 PhD candidates in 6 countries, 9 of which are in the process of completing their studies; over 100 PhD research outputs were produced within the Engage timeframe	• D5.18, D5.19, D5.20, D5.21, D5.22, D5.23, D5.24, D5.25, D5.26, D5.27 (each report summarises a PhD)
	3 introductory courses were prepared by Engage which are available for use by any academic institution, free of charge (from the EngageWiki); the courses cover (1) an introduction to air traffic management, (2) airline planning and operations, and (3) airport planning and operations	• D5.15 (course overview)
	3 annual summer schools were organised (1 physical in 2019, 2 virtual 2020-2021); over 200 participants attended the 3 summer schools, consisting of PhD/Masters students, researchers and industry representatives	• D5.12 (summer school 2019) • D5.13 (summer school 2020) • D5.14 (summer school 2021)
	Engage supported the production of 50 open access publications by PhDs and CF projects	• D1.2 (FPRR) • D2.2 (C&D reporting); see also Engage outputs listed in CORDIS [61]

2.5 Technical Deliverables

The following table summarises all the technical deliverables. Note that some of the deliverable titles were adjusted from those foreseen in the Grant Agreement, to better reflect the content. Content in some of the earlier deliverables has been superseded by later deliverables. For example, D5.1 and D5.3 describe initial versions of wiki databases, whereas D3.9 describes the final content.

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Table 15: Project Deliverables

Reference	Title	Delivery Date[9]	Dissemination Level[10]
	Description		
D1.1	Management Plan	07/02/2019	Confidential
This document is the Project Management Plan (PMP) of the Exploratory Research action Engage. The PMP documents the management plan and procedures, complementing the project information provided in the Grant Agreement Description of Action with additional detail.			
D1.2	Final Project Results Report	07/10/2022	Public
This deliverable summarises the activities and results of Engage, the SESAR 2020 Knowledge Transfer Network (KTN). The KTN initiated and supported multiple activities for SESAR and the European air traffic management (ATM) community, including PhDs, focused catalyst fund projects, thematic workshops, summer schools and the launch of a wiki as the one-stop, go-to source for ATM research and knowledge in Europe. Key throughout was the integration of exploratory and industrial research, thus expediting the innovation pipeline and bringing researchers together. These activities laid valuable foundations for the SESAR Digital Academy.			
D2.1	Communication plan, website, and visual identity material	01/02/2018	Public
The purpose of this document is to describe the dissemination plan, dissemination policy and initial dissemination products of the Exploratory Research action Engage, taking into account its specifications and the target audience.			
D2.2	Final Communication and Dissemination Report	25/08/2022	Public
This deliverable reports on the communication and dissemination activities carried out by the Engage consortium over the duration of the network. Planned activities have been adapted due to the Covid-19 pandemic, however a full programme of workshops and summer schools has been organised. Support has been given to the annual SESAR Innovation Days conference and there has been an Engage presence at many other events. The Engage website launched in the first month of the network. This was later joined by the Engage 'knowledge hub', known as the EngageWiki, which hosts ATM research and knowledge. The wiki provides a platform and consolidated repository with novel user functionality, as well as an additional channel for the dissemination of SESAR results. Engage has also supported and publicised numerous research outputs produced by PhD candidates and catalyst fund projects.			
D2.5	Annual combined thematic workshops progress report (priming wave 1)	25/01/2019	Public
The preparation, organisation and the conclusions from the three thematic challenge workshops held in 2018 are described. The preparation and expert consultation results are reported for the "Vulnerabilities and global security of the CNS/ATM system" challenge workshop, scheduled to take place at a later date.			

[9] Delivery data of latest edition
[10] Public or Confidential

Reference	Title	Delivery Date[9]	Dissemination Level[10]
	Description		
D2.6	Annual combined thematic workshops progress report (series 2)	26/02/2021	Public
The preparation, organisation and conclusions from the thematic challenge workshops, two ad hoc technical workshops, a technical session on data and a MET/ENV workshop held in 2019 and 2020 are described. Partly due to Covid-19, two of the 2020 thematic challenge workshops scheduled to take place at the end of 2020 were re-scheduled to January 2021. We also report on the preparation for these two workshops, while the conclusions will be included in the next corresponding deliverable.			
D2.7	Annual combined thematic workshops progress report (series 3)	17/11/2021	Public
This deliverable reports on the organisation and results obtained from the third and fourth editions of the Engage thematic challenge (TC) workshops held in 2021. Due to the Covid-19 pandemic, the third editions of the TC2 and TC3 workshops, initially scheduled to be held in 2020, were delayed to the beginning of 2021. The TC1 and TC4 workshops reached their third edition in 2021, while TC2 and TC3 closed with the fourth edition. The main lessons learned relate to data availability, collaboration opportunities, machine learning and artificial intelligence methodologies and approaches, and incentives for future ATM implementations.			
D2.8	8th SESAR Innovation Days report	22/01/2019	Public
This report describes the eighth edition of the SESAR Innovation Days, which took place in Salzburg, Austria between 03-07 December 2018.			
D2.9	9th SESAR Innovation Days report	15/01/2020	Public
This report describes the ninth edition of the SESAR Innovation Days, which took place in Athens, Greece, 02-06 December 2019.			
D2.10	10th SESAR Innovation Days report	04/03/2021	Public
This report describes the tenth edition of the SESAR Innovation Days, which took place as a virtual event between 07-10 December 2020.			
D2.11	11th SESAR Innovation Days report	22/04/2022	Public
This report describes the eleventh edition of the SESAR Innovation Days, which took place as a virtual event between 07-09 December 2021.			
D3.1	Final workshop presentations of wave 1 catalyst-funded projects	20/04/2021	Public
This deliverable collates the final presentations of catalyst-funded wave 1 projects, given at Engage thematic challenge workshops.			
D3.2	Final workshop presentations of wave 2 catalyst-funded projects	29/01/2022	Public
This deliverable collates the final presentations of catalyst-funded wave 2 projects, given at Engage thematic challenge workshops and associated events.			
D3.4	Thematic challenges priming report for first workshops	21/06/2018	Public

Reference	Title	Delivery Date[9]	Dissemination Level[10]
Description			
This document describes the process used by the Engage KTN to select the thematic challenges central to the network and how these are being used to define its first set of workshops.			
D3.5	Opportunities for innovative ATM research (interim report)	26/07/2019	Public
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 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.			
D3.6	Opportunities for innovative ATM research	18/08/2022	Public
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 3 Joint Undertaking. This report highlights future research opportunities for ATM. The basic framework is structured around three research pillars. Each research pillar has a dedicated section in this report. SESAR's Strategic Research and Innovation Agenda, Digital European Sky is a focal point of comparison. Much of the work is underpinned by the building and successful launch of the Engage wiki, which comprises an interactive research map, an ATM concepts roadmap and a research repository. Extensive lessons learned are presented. Detailed proposals for future research, plus research enablers and platforms are suggested for SESAR 3.			
D3.7	Update on the Engage repository and knowledge hub functionality (initial)	25/03/2020	Public
This initial report describes the planned functionality and features of the forthcoming Engage wiki and establishes the scope of the ATM concepts roadmap.			
D3.8	Mapping ATM research concepts, past and future - including the Engage wiki implementation	16/02/2021	Public
This report presents the wiki produced by Engage, SESAR's Knowledge Transfer Network. It summarises the key development processes, status and planning for the wiki, which has been built over the past two years, with increased activity in 2020 to resolve underlying data provision issues. *Inter alia*, the wiki hosts the first interactive research map of European ATM, an ATM concepts roadmap, the first consolidated listing of European university programmes, and sets out progress towards a new, one-stop (data) repository for the research community.			
D3.9	The Engage wiki - an update on the KTN's knowledge hub functionality, research maps and repository	18/08/2022	Public
This report is a reference document for the Engage wiki. It summarises the key features developed, their status and the legacy planning for the wiki. Inter alia, the wiki hosts the first interactive research map of European ATM, an ATM concepts roadmap, the first consolidated listing of European university programmes and a new, one-stop (data) repository for the research community. Key outputs and results enabled through the wiki, such as mapping research gaps, are discussed in Engage D3.10, which focuses specifically on opportunities for innovative ATM research. These deliverables comprise a pair of legacy deliverables of particular use and importance for any KTN launched within the SESAR 3 Exploratory Research programme.			
D3.10	Research and innovation insights	18/08/2022	Public

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Reference	Title	Delivery Date[9]	Dissemination Level[10]
Description			
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. This report highlights future research opportunities for ATM. The basic framework is structured around three research pillars. Each research pillar has a dedicated section in this report. SESAR's Strategic Research and Innovation Agenda, Digital European Sky is a focal point of comparison. Much of the work is underpinned by the building and successful launch of the Engage wiki, which comprises an interactive research map, an ATM concepts roadmap and a research repository. Extensive lessons learned are presented. Detailed proposals for future research, plus research enablers and platforms are suggested for SESAR 3.			
D4.1	Wave 1 catalyst fund project final report: Probabilistic weather avoidance routes for medium-term storm avoidance ('PSA-Met')	03/03/2021	Public
This is the final technical report of the *Probabilistic weather avoidance routes for medium-term storm avoidance ('PSA-Met')* project, which was awarded funding through the Engage KTN's first Call for catalyst funding.			
D4.2	Wave 1 catalyst fund project final report: airport-sCAle seveRe weather nowcastinG project ('CARGO')	23/04/2021	Public
This is the final technical report of the *Airport-scale severe weather nowcasting project ('CARGO')*, which was awarded funding through the Engage KTN's first Call for catalyst funding.			
D4.3	Wave 1 catalyst fund project final report: Authentication and integrity for ADS-B	07/04/2021	Public
This is the final technical report of the *Authentication and integrity for ADS-B* project, which was awarded funding through the Engage KTN's first Call for catalyst funding.			
D4.4	Wave 1 catalyst fund project final report: Data-driven trajectory imitation with reinforcement learning	03/03/2021	Public
This is the final technical report of the *Data-driven trajectory imitation with reinforcement learning* project, which was awarded funding through the Engage KTN's first Call for catalyst funding.			
D4.5	Wave 1 catalyst fund project final report: A Data-drIven approach for dynamic and Adaptive trajectory PredictiON ('DIAPasON')	07/04/2021	Public
This is the final technical report of *A Data-drIven approach for dynamic and Adaptive trajectory PredictiON ('DIAPasON')* project, which was awarded funding through the Engage KTN's first Call for catalyst funding.			
D4.6	Wave 1 catalyst fund project final report: Operational alert Products for ATM via SWIM ('OPAS')	03/03/2021	Public
This is the final technical report of the *Operational alert Products for ATM via SWIM ('OPAS')* project, which was awarded funding through the Engage KTN's first Call for catalyst funding.			
D4.7	Wave 1 catalyst fund project final report: An interaction metric for an efficient traffic demand management: requirements for the design of data-driven protection mechanisms ('INTERFACING')	22/04/2021	Public

Reference	Title	Delivery Date[9]	Dissemination Level[10]
Description			
This is the final technical report of *An interaction metric for an efficient traffic demand management: requirements for the design of data-driven protection mechanisms ('INTERFACING')* project, which was awarded funding through the Engage KTN's first Call for catalyst funding.			
D4.8	Wave 1 catalyst fund project final report: MET enhanced ATFCM	03/03/2021	Public
This is the final technical report of the *MET enhanced ATFCM* project, which was awarded funding through the Engage KTN's first Call for catalyst funding.			
D4.9	Wave 1 catalyst fund project final report: Exploring future UDPP concepts through computational behavioural economics	20/04/2021	Public
This is the final technical report of the *Exploring future UDPP concepts through computational behavioural economics* project, which was awarded funding through the Engage KTN's first Call for catalyst funding.			
D4.10	Wave 1 catalyst fund project final report: The drone identity - investigating forensic-readiness of U-Space services	03/03/2021	Public
This is the final technical report of *The drone identity - investigating forensic-readiness of U-Space services* project, which was awarded funding through the Engage KTN's first Call for catalyst funding.			
D4.11	Wave 2 catalyst fund project final report: Proof-of-concept: practical, flexible, affordable pentesting platform for ATM/avionics cybersecurity ('ATM-cybersec')	22/12/2021	Public
This is the final technical report of the *Proof-of-concept: practical, flexible, affordable pentesting platform for ATM/avionics cybersecurity ('ATM-cybersec')* project, which was awarded funding through the Engage KTN's second Call for catalyst funding.			
D4.12	Wave 2 catalyst fund project final report: Safe drone flight - assuring telemetry data integrity in U-Space scenarios ('SDF')	03/12/2021	Public
This is the final technical report of the *Safe drone flight - assuring telemetry data integrity in U-Space scenarios ('SDF')* project, which was awarded funding through the Engage KTN's second Call for catalyst funding.			
D4.13	Wave 2 catalyst fund project final report: Flight centric ATC with airstreams ('FC2A')	03/12/2021	Public
This is the final technical report of the *Flight centric ATC with airstreams ('FC2A')* project, which was awarded funding through the Engage KTN's second Call for catalyst funding.			
D4.14	Wave 2 catalyst fund project final report: Meteo Sensors In the Sky ('METSIS')	17/11/2021	Public
This is the final technical report of the *Meteo Sensors In the Sky ('METSIS')* project, which was awarded funding through the Engage KTN's second Call for catalyst funding.			

Reference	Title	Delivery Date[9]	Dissemination Level[10]
	Description		
D4.15	Wave 2 catalyst fund project final report: Probabilistic information Integration in Uncertain data processing for Trajectory Prediction ('PIU4TP')	23/11/2021	Public
This is the final technical report of the *Probabilistic information Integration in Uncertain data processing for Trajectory Prediction ('PIU4TP')* project, which was awarded funding through the Engage KTN's second Call for catalyst funding.			
D4.16	Wave 2 catalyst fund project final report: Collaborative cyber security management framework	31/12/2021	Public
This is the final technical report of the *Collaborative cyber security management framework* project, which was awarded funding through the Engage KTN's second Call for catalyst funding.			
D4.17	Wave 2 catalyst fund project final report: Role of Markets in AAS Deployment ('RoMiAD')	15/03/2022	Public
This is the final technical report of the *Role of Markets in AAS Deployment ('RoMiAD')* project, which was awarded funding through the Engage KTN's second Call for catalyst funding.			
D4.18	Wave 2 catalyst fund project final report: Weather impact prediction for ATFCM ('WIPA')	21/04/2022	Public
This is the final technical report of the *Weather impact prediction for ATFCM ('WIPA')* project, which was awarded funding through the Engage KTN's second Call for catalyst funding.			
D5.1	University programme database (initial version)	15/05/2019	Public
This document describes the methodology applied to the design and population of the initial version of the university programme database. The database contains information on postgraduate degree and research opportunities.			
D5.3	Postgraduate research and events database (initial version)	04/04/2019	Public
This document describes the methodology applied to the design and population of the initial version of the postgraduate research and events database. The database contains information on European and international conferences, workshops, summer schools, training courses and other relevant events.			
D5.6	Thematic challenge briefing notes (1st and 2nd releases)	10/02/2022	Public
Engage identified four thematic challenges to address research topics not contemporaneously (sufficiently) addressed by SESAR. This deliverable serves primarily as a record of the two sets of released thematic challenge briefing notes.			
D5.7	PhD reporting end year 1	31/10/2021	Confidential
In this deliverable we summarise the progress achieved by Engage PhDs during the first year, based on the initial six-month PhD reports received and assessed for each PhD project.			
D5.11	PhD final reporting; handover planning and contingencies	24/08/2022	Confidential

Reference	Title	Delivery Date[9]	Dissemination Level[10]
Description			
This confidential deliverable summarises the progress achieved by Engage PhDs from the second year to the closure of Engage. All Engage PhDs have submitted their final reporting and the final summary reports have been published.			
D5.12	Engage SESAR Summer School 2019	16/03/2020	Public
This report describes the first edition of the Engage SESAR summer school, which took place in Belgrade, Serbia, between 09-13 September 2019.			
D5.13	Engage SESAR Summer School 2020	13/11/2020	Public
This report describes the second edition of the Engage SESAR summer school, which was held as a virtual event, between 21-25 September 2020.			
D5.14	Engage SESAR Summer School 2021	15/03/2022	Public
This report describes the third edition of the Engage SESAR summer school, which was held as a virtual event, between 30 August - 02 September 2021.			
D5.15	Production of three-part introductory courses	10/08/2021	Public
This deliverable summarises the preparation of three introductory courses that are available for use by any academic institution, free of charge, via the EngageWiki. The contents of the courses cover: (1) an introduction to air traffic management; (2) airline planning and operations; and (3) airport planning and operations.			
D5.17	GEN-INTRO training sessions	31/03/2022	Confidential
This report logs the provision of Engage-supported places on GEN-INTRO training courses between 2019 and 2021.			
D5.18	PhD final report: Decision support system for airline operation control hub centre ('DiSpAtCH')	19/08/2022	Public
This is the final report of the Decision support system for airline operation control hub centre ('DiSpAtCH') PhD, which was awarded funding through the Engage KTN's Call for PhDs and post-graduate theses. This report provides a summary of the research in advance of the published PhD thesis, which can be accessed directly from the Technische Universität Braunschweig (the link is provided in Section 11.1).			
D5.19	PhD final report: Trajectory planning for conflict-free trajectories: a multi agent reinforcement learning approach (RL4CFTP)	13/07/2022	Public
This is the final report of the *Trajectory planning for conflict-free trajectories: a multi agent reinforcement learning approach* PhD, which was awarded funding through the Engage KTN's Call for PhDs and post-graduate theses. This report provides a summary of the research in advance of the published PhD thesis, which can be accessed directly from the University of Piraeus (the link is provided in Section 11.1).			
D5.20	PhD final report: Detection, classification, identification and mitigation of GNSS signal degradations by means of machine learning	05/08/2022	Public

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Reference	Title	Delivery Date[9]	Dissemination Level[10]
Description			
This is the final report of the Detection, classification, identification and mitigation of GNSS signal degradations by means of machine learning PhD, which was awarded funding through the Engage KTN's Call for PhDs and post-graduate theses. This report provides a summary of the research, which is two-thirds complete but on hiatus following the departure of the candidate. The code has been published by the Ecole Nationale de l'Aviation Civile (the link is provided in Section 11.1).			
D5.21	PhD final report: Machine learning for aircraft trajectory prediction: a solution for pre-tactical air traffic flow and capacity management	05/08/2022	Public
This is the final report of the Machine learning for aircraft trajectory prediction: a solution for pre-tactical air traffic flow and capacity management PhD, which was awarded funding through the Engage KTN's Call for PhDs and post-graduate theses. This report provides a summary of the research in advance of the published PhD thesis, which can be accessed directly from the Universitat Politècnica de Catalunya (the link is provided in Section 11.1).			
D5.22	PhD final report: Deep Multi-Agent Reinforcement Learning Applications in ATM	23/08/2022	Public
This is the final report of the Deep Multi-Agent Reinforcement Learning Applications in ATM PhD, which was awarded funding through the Engage KTN's Call for PhDs and post-graduate theses. This report provides a summary of the research in advance of the published PhD thesis, which can be accessed directly from the Universitat Autònoma de Barcelona (the link is provided in Section 11.1).			
D5.23	PhD final report: Integrating weather prediction models into ATM planning ('IWA')	27/05/2022	Public
This is the final report of the *Integrating weather prediction models into ATM planning ('IWA')* PhD, which was awarded funding through the Engage KTN's Call for PhDs and post-graduate theses. This report provides a summary of the research in advance of the published PhD thesis, which can be accessed directly from Linköping University (the link is provided in Section 11.1).			
D5.24	PhD final report: Advanced statistical signal processing for next generation trajectory prediction	06/07/2022	Public
This is the final report of the *Advanced statistical signal processing for next generation trajectory prediction* PhD, which was awarded funding through the Engage KTN's Call for PhDs and post-graduate theses. This report provides a summary of the research in advance of the published PhD thesis, which can be accessed directly from the Universitat Politècnica de Catalunya (the link is provided in Section 11.1).			
D5.25	PhD final report: A pilot/dispatcher support tool based on the enhanced provision of thunderstorm forecasts considering its inherent uncertainty ('STORMY')	19/07/2022	Public
This is the final report of *'STORMY' – A pilot/dispatcher support tool based on the enhanced provision of thunderstorm forecast considering it inherent uncertainty* PhD, which was awarded funding through the Engage KTN's Call for PhDs and post-graduate theses. This report provides a summary of the research in advance of the published PhD thesis, which can be accessed directly from the Universidad Carlos III de Madrid (the link is provided in Section 11.1).			
D5.26	PhD final report: Second generation agent-based modelling for improving APOC operations	19/07/2022	Public

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Reference	Title	Delivery Date[9]	Dissemination Level[10]
Description			
This is the final report of the *Second generation agent-based modelling for improving APOC operations* PhD, which was awarded funding through the Engage KTN's Call for PhDs and post-graduate theses. This report provides a summary of the research in advance of the published PhD thesis, which can be accessed directly from the Ecole Nationale de l'Aviation Civile (the link is provided in Section 11.1).			
D5.27	PhD final report: Resource constrained airline ground operations optimizing schedule recovery under uncertainty	25/06/2022	Public
This is the final report of the *Resource constrained airline ground operations optimizing schedule recovery under uncertainty* PhD, which was awarded funding through the Engage KTN's Call for PhDs and post-graduate theses. This report provides a summary of the research in advance of the published PhD thesis, which can be accessed directly from the Technische Universität Dresden (the link is provided in Section 11.1).			

3 Links to SESAR Programme

3.1 Contribution to the ATM Master Plan

Although the Engage project did not provide any direct contribution to the Master Plan, it is certainly possible and desirable that the outcome of the different threads of activities carried out within the Engage framework (e.g. thematic challenges, catalyst fund projects) can lead to a contribution to the ATM Master Plan once they achieve a higher level of maturity.

3.2 Maturity Assessment

Due to the nature of the Engage project, and in coordination with the S3JU, the required Maturity Assessment is not applicable.

4 Conclusion and Lessons Learned

4.1 Conclusions

This first concluding section summarises the proposed research directions, and then on the corresponding platforms in the lessons learned section. Further reporting of the proposed research directions can be found in D3.10 (specifically Sections 2.3.3, 2.4.3 and 2.5.3).

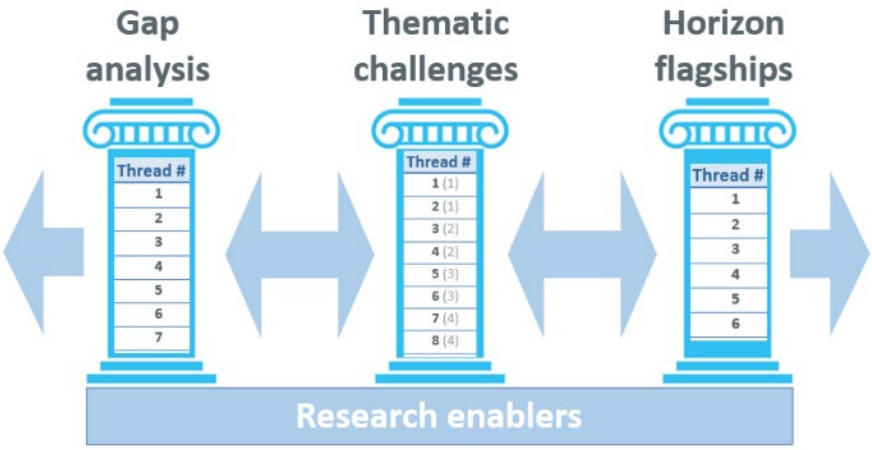

Figure 10: Research pillars, threads and enablers

Figure 10 shows the three research pillars. each of which may be conceived of as comprising various 'threads', i.e. their key component research ideas. These threads are summarised in the following tables.

The pillars are shown in 2D, although they conceptually lie along three non-orthogonal axes. There are many relationships between the threads that may be explored further, using a mixture of qualitative (expert-led) and quantitative (data-driven) approaches.

An initial qualitative analysis is likely to bring new insights and synergies. (It is remarkable how many of the threads in the gap analysis and thematic challenge pillars, for example, are related to even just the first two threads of the horizon flagships, viz. quantum computing and strong AI). It is expected, and suggested, that other interdisciplinary insights and technical advances be brought into this landscape, both to help navigate and shape it, and to provide the tools for its development through new research and innovation (R&I).

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Table 16: Research threads for the gap analysis pillar & relationships with SRIA flagships

Thread	SRIA flagship(s)	Summary
Additional focus on safety performance	1 	**Connected and automated ATM**: The SRIA has not allocated safety as an area of specific work *per se*, but rather as a horizontal performance criterion forcing safety evaluations to be undertaken in each area. However, the foreseen contributions of the nine flagship activities to the safety dimension seem to be quite modest, from "maintaining" to "maintained if not improved", falling rather short, it seems, of earlier ACARE/SES objectives of a ten-fold safety improvement. This flagship (connected and automated ATM) aims at higher levels of automation and specific tools for safety improvement in higher levels of automation. It would be of value to stress even more the need for a well-designed and executed safety assessment, as that is usually the stepping stone for faster development and deployment, especially for safety-critical innovations. Approaches to safety assessment developed since SESAR 1 could add value here.
Developing techniques for dynamic risk modelling	1, 2 	**Connected and automated ATM; Air-ground integration and autonomy:** These two flagships propose research into safety-critical areas, which require rigorous safety assessments. It would be of value to stress the need for well-designed and executed safety assessments for research performed in these flagships (also for other flagships, but the link to these two is more critical). However, it is readily acknowledged that material on the application of dynamic risk modelling is included in the *Guidance to Apply SESAR Safety Reference Material*, whereas it would be endorsed that actual safety assessments should deploy tools specific to the safety requirements in question.
Enhanced surface/vehicle driver guidance and airport DCB	1 	**Connected and automated ATM:** The SRIA formulation addresses airports in two areas: "connected and automated ATM" and "multimodal and passenger experience". Enhanced surface/vehicle driver guidance and airport DCB might further be developed particularly under the high-level R&I need/challenge of "Airport automation including runway and surface movement assistance for more predictable ground operations" outlined within the former flagship.
Ideation and ER in airports (performance) domain	8 	**Artificial intelligence (AI) for aviation**: Whilst the SRIA seems to attach rather less importance to the role of airports in this flagship, some of the airport-related work lends itself very well to ML approaches. The topic covering the airports (performance) domain is not necessarily linked to AI, but many applications, especially digitalisation, can be achieved using AI and ML techniques to build innovative and more advanced performance frameworks.
Market-uptake and incentivising airspace users, with performance simulations	2 	**Air-ground integration and autonomy:** Market-uptake and incentivising airspace users, for example for TBS (time-based separation) systems could loosely fit in the flagship on air-ground integration and autonomy, developing further the assessments needed for TBS (or other similar) business cases. Such research requires deeper economic and market mechanisms investigations, as well as network-level performance simulations.
Advanced AI/ML to predict loads and propose sector configurations	8 	**Artificial intelligence (AI) for aviation**: Research into advanced AI/ML techniques to predict sector loads and propose sector configurations would seem to be potentially accommodated in the capacity-on-demand and dynamic airspace flagship, but would in fact most likely fit better in the artificial intelligence (AI) for aviation flagship if the goal were to be to develop and use advanced AI/ML-based techniques predicatively.

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Thread	SRIA flagship(s)	Summary
Extended UDPP research	3 	**Capacity-on-demand and dynamic airspace:** UDPP research is contained within this flagship, aiming at extending the concept, but not mentioning explicitly inter-airline slot swaps or specific indicators to explore. Definitions of equity and fairness across all stakeholders, and analyses of the corresponding trade-offs, would clearly bring important added value to the research in this flagship.

From the data-driven perspective, the search space that the axes define is a rich environment for exploring future research, for example using the multi-dimensional vectorisation approach for the gap analysis, using an auto-encoder (unsupervised ML) model. This environment and such activities may be supported by the enablers and platforms (for research) described in next section (several of which themselves require further research activity and development), and of course by other enablers.

Table 17: Research threads for the thematic challenges pillar & relationships with SRIA flagships

Thread	SRIA flagship(s)	Summary
Establish and develop a SESAR 3 cybersecurity community	5 	**Virtualisation and cyber-secure data sharing:** This flagship addresses several high-level R&I needs/challenges, with that of 'cyber resilience' describing the need for monitoring and adapting to the changing threat landscape and emergence of new actors, aiming at the development of cyber-resilience guidelines and procedures tailored to ATM. However, a large and positive impact could be obtained through continuous collaboration and updates within a dedicated SESAR 3 cybersecurity community. This flagship is the place for setting up such guidelines and procedures, although not necessarily the best place for the establishment and nurturing of a cyber community, which might be developed through the SESAR 3 KTN or Digital Academy, overarching the flagship and its corresponding work components and actors.
Support a culture of responsible disclosure & sharing experimental scenarios	5 	**Virtualisation and cyber-secure data sharing:** A major high-level R&I need/challenge in this flagship, where responsible disclosure and sharing experimental scenarios could bring added value, is "Free flow of data among trusted users across borders", which foresees: "The sharing of data through interoperable platforms and, the exchange of open data between trusted partners, combined with open architecture policies [...]". This added value should be flagged explicitly, i.e. to add responsible disclosure between trusted partners. Additionally, sharing experimental scenarios (and experimental data) applies to all the areas of SESAR 3 programme, and each flagship would benefit from this.
Explainable AI: explore trade-offs between explainability and performance	8 	**Artificial intelligence (AI) for aviation**: This flagship focuses on research and development of AI for aviation, aiming to develop new "methodologies for the validation and certification of advanced automation that ensure transparency, legal aspects, robustness and stability", to foster higher automation and use of AI in all phases of planning and execution. The exploration of trade-offs between explainability and performance should bring new knowledge to the flagship, possibly enabling faster development and implementation of AI algorithms in certain areas (most probably non safety-critical ones).

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Thread	SRIA flagship(s)	Summary
Artificial datasets for ML: avoiding training on already-cleaned scenarios	8 	**Artificial intelligence (AI) for aviation**: Different aspects of AI and ML algorithm development are discussed in the SRIA, among them the high-level R&I need/challenge "AI Improved datasets for better airborne operations", which mainly describes the possibilities from fitting new sensors and higher volumes of communication between air and ground. This flagship would benefit from taking into account the two key aspects of datasets for ML identified through the KTN's investigations: a need for data not including pre-intervention by other entities and having sufficient data points for training ML algorithms, e.g. through artificial training datasets.
Climate impact: mitigation and metrics	7 	**Aviation Green Deal:** This SRIA flagship refers to non-CO_2 impacts on the climate. The flagship would, however, benefit from further description and focus on defining the measurement for all components of aviation emissions, which would help to assess the impact of new technologies, such as aircraft with electric or hydrogen propulsion, and (on-going) SESAR Solutions. This aligns closely with defining new environmental indicators, which would support the development of the SESAR 3 Performance Framework.
Further modelling of uncertainty in weather forecasts and climate impacts	1, 7 	**Aviation Green Deal:** This flagship specifically mentions the need for the development of an environmental impact assessment methodology and new metrics, to be able to take climate impact into account properly. Inclusion of uncertainty is of paramount importance in this area. **Connected and automated ATM:** Improved weather forecasts are mentioned in this flagship, with the aim of improving trajectory advisories by taking into account various uncertainties. The inclusion and explanation of uncertainties in the forecasts would improve the tools for trajectory prediction and thus network performance in general.
Incentivising early adopters: economic and behavioural mechanisms	5 	**Virtualisation and cyber-secure data sharing**: This SRIA flagship addresses virtualisation and some aspects of regulatory and service evolution needed. The flagship would benefit from the assessment of incentivisation of various stakeholders, linked to different business models, that would be appropriate in the European ATM market, to expedite this transition. To achieve the largest benefits for the system, the emphasis should be on speed of uptake, and those stakeholders that want to move quickly, should be supported to do so.
Creating flexible services: ops data licencing, sovereignty and accessibility	5 	**Virtualisation and cyber-secure data sharing**: This flagship acknowledges the importance of data and data sharing, planning work on these aspects. Currently, almost all data in ATM are considered in need of being protected, which is not necessarily true. The flagship would benefit from a more detailed approach to the development, and licensing of new business models, including data certification, needed in the transformation towards the Airspace Architecture Study [114] vision, also tackling the issue of data sovereignty and cross-State sharing.

Having set the scene and furnished a wealth of ideas for follow-on research, possibly but not only in any KTN launched in SESAR 3, we recommend that such priorities could be best assessed in 2022-23 with a parallel review of ER4 progress and in light of the projects funded in response to the first ER Call in SESAR 3. On-going work such as the Innovation Hub initiative from EUROCONTROL should also be consulted for potential collaborative opportunities and inspiration. As flagged, we recommend that this first step be qualitative, and expert-led. This could be co-reviewed with the new Scientific Advisory Body of SESAR 3, should the S3JU consider this appropriate.

Through the EngageWiki, the research community has at its disposal ready-made fora for supporting such future ideation and knowledge exchange, a repository in which to store data and code, and a

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roadmap into which future results may be integrated. The wiki's interactive research map may also be used as a preliminary tool to search the research space. New work initiatives could be taken up through (revised) thematic challenges, with supporting catalyst fund projects and PhDs, and matured through a further series of workshops.

Some of the practicalities for taking such work forward, and our recommendations for the supporting platforms, are presented in the next section.

Table 18: Research threads for the horizon flagships pillar & relationships with SRIA flagships

Thread	SRIA flagship(s)	Summary
Quantum computing	8 	**Artificial intelligence (AI) for aviation:** whilst the strongest correspondence of quantum computing is unsurprisingly with the 'AI' flagship, the wider implications for this new technology are very broad and deep, considering the applications of much faster solutions to search space and combinatorial problems, potentially offering vastly improved capabilities both for operational/tactical searches of improved solutions to complex capacity constraints in ATM, and e.g. (safety) validation. Exposing cybersecurity vulnerabilities and supporting public key cryptographic systems are clearly important in the ATM context regarding not only CNS, but also in the context wider of information exchange over networks, supporting SWIM and privileged data exchange (e.g. for UDPP).
Strong AI	8, 1 	**Artificial intelligence (AI) for aviation:** the strongest correspondence of strong AI is not unexpectedly with the 'AI' flagship, which cites "AI for prescriptive aviation". Whilst strong AI represents a step-shift in the state of the art, it builds on the current science, for example, whereby the coupling of advanced sensor technologies with ML/AI techniques, could support system development in multiple contexts, such as risk mitigation, system diagnoses, performance assessment, forecasting, predictive support and design. **Connected and automated ATM:** may be supported specifically through more efficient resource allocation for humans and machines, although this is just one of many other SRIA flagships potentially impacted strategically and tactically e.g. through strong AI's foresight capabilities, 'strong emergence' and policy generation.
Integrated ticketing and virtual interlining	6 	**Multimodality and passenger experience:** fully logically, this represents the strongest SRIA flagship correspondence with integrated ticketing and virtual interlining. An examination of existing virtual interlining models and online travel agencies would give better insights into the implications for airspace users, airport infrastructure requirements and other modal travel service providers (e.g. rail). Operationally, the impacts on holding flights for delayed trains, and *vice versa*, could be significant – further metric development and scenario simulations are required. Future travel operators should offer appropriate connection guarantees and passenger needs in case of disruption, throughout the booked travel in a door-to-door context. The SRIA discusses ticketing, integration and crisis management.

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Thread	SRIA flagship(s)	Summary
European risk register for ATM and air transport resilience	8 	**Artificial intelligence (AI) for aviation:** "resilience" is mentioned often in the SRIA, mostly with reference to cybersecurity, but also flagging climate/meteorological resilience (**Aviation Green Deal**) and passenger journey resilience (**Multimodality and passenger experience**). Comparably strong associations for the risk register thread from Engage with the SRIA 'AI' flagship result from common references to resilience, machine learning, complexity and networks. Complexity science and complex network theory have already proven in ATM to be well-suited tools and metrics for network resilience. It would be informative to explore lessons learned from the Covid-19 pandemic, e.g. in terms of the sustainability of current financial, business and performance assessment models for airspace users and ANSPs.
Improved route emissions metrics and policies	7, 6 	**Aviation Green Deal:** regarding the need for improved route emissions metrics and policies, this flagship addresses the specific high-level R&I needs/challenges of 'Optimum green trajectories' and 'Non-CO_2 impacts of aviation', in addition to an 'environmental dashboard' relating to metric development and implementation, impact assessment trade-offs, and incentivisation considerations. Regarding links with the **Multimodality and passenger experience** SRIA flagship, the Engage thread stresses the current relatively passive role of passengers in flight sustainability, whereas strengthened national and international policy (taxes) and data transparency may generate a stronger passenger link with airline decision-making and business models, also in the multimodal context.
ATM-U-space coordination; UAM access mechanisms	4, 2 	**U-space and urban air mobility** and **Air-ground integration and autonomy**: the correspondence between these two SRIA flagships and research directions flagged by Engage is self-evident. The latter notes that manned aviation may well be present in VLL airspace, with drones: equipage requirements, management of non-nominal/emergency situations and common services need to be developed. The vicinity of airports, in which different vehicle types will operate, with infringement risks, is of particular interest. There is a strong link with the Smart City concept. Access to U-space and UAM airspace will have to be based on equipage requirements and respect principles of equity, whilst applying yet-to-be-defined priority rules, e.g. for emergency and security flights. DCB raises further challenges in this context.

4.2 Technical Lessons Learned

The key lessons learned per network activity are summarised in the following sections. Further lessons learned can be found in specific deliverables.

Research platforms

Lessons learned related to research platforms were reported in D3.9 and D3.10; the key points include:

Sources of project data – consolidation and recency:

- The Engage research repository (with its search and filtering functionalities) together with CORDIS and the individual SESAR project's websites provide a range of sources for accessing data regarding SESAR projects. The extent to which it is desired to consolidate these processes

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and focus on one single source, is a question for the S3JU and, potentially, any successor KTN to Engage. Whatever the approach taken, the value of a single source of regularly updated data, with analytical functionality, also embracing the wider ATM research environment has received strong endorsement from the user community. Such data should, in future, include not only catching up with SESAR 2020 (e.g. ER4), but move forward to projects funded through SESAR 3 Calls, and material from other non-SESAR industrial research programmes, and maintain the main conference materials already encompassed. Other open access papers could also be added. Such data could be incorporated into the interactive research map and ATM concepts roadmap on an annual basis.

- Further challenges to be overcome include obtaining such project data (i.e. SESAR deliverables) in a timely fashion (sometimes there is a significant period between initial submissions (which themselves are often delayed) and final approval, thus permitting public release), and the incentive or requirement for projects to make such deliverables available directly to a third party (such as a KTN). Whilst the repository contains materials as recent as 2021, most of the identified weakest links in the gap analysis related to work delivered around 2016. This was of course aligned with the objective of looking at retrospective gaps, whilst underlining the need for expert interpretation of the algorithmic outputs.

Wiki registration and security:

- Like all wikis, the EngageWiki was subject to a bot attack, temporarily disrupting service. After this happened, the user registration process was filtered through a form included in the wiki. Each user request is now sent by e-mail to an account managed by the consortium. Every user has to complete an information form, so the wiki managers can double check that they are not a bot 'user' and that they have an appropriate profile (e.g. ATM-, aviation-, research-related, etc.). Once this information has been checked, it is individually approved or denied. After this system was implemented, the user registrations related to bots were fewer than ten. This system, although not automatic, has proven useful and secure.
- Wiki documents are hosted in Amazon Web Services, chosen over other services mainly due to the security it offers, added to the fact that it is easy to use and manage, with unlimited storage data.

Wiki discussion fora:

- It is recommended that the wiki discussion fora be further deployed to gather sufficient momentum to become hubs for various communications and discussions in SESAR 3, e.g. hosting discussions around specific technical sessions of the SIDs or to encourage inter-project researcher collaboration across a SESAR 3 research topic (e.g. multimodality), even integrating across ER-IR on specific issues.

Research enablers

Lessons learned related to research enablers were reported in D3.10; the key points include:

Data and code issues:

- **Data availability** is a well-recognised bottleneck in exploratory research. It is often difficult to obtain, and the same dataset often cannot be used in multiple projects. This is a barrier to improving experimental comparability across projects. Many projects and/or PhDs lose many

months (or more) in trying to obtain (and consolidate and clean) data, and this was a recurring theme throughout the Engage thematic challenge workshops. Different types of data are required across ER work. Some of the data can be obtained freely (e.g. from the relatively new, and extensive, EUROCONTROL R&D data archive [116], launched at the 2nd summer school; ADS-B data from the OpenSky Network [117]), some need to be paid for (e.g. schedule data, passenger itineraries and fares), and some need to be acquired from multiple sources if a greater geographical area is being researched (e.g. MET lightning or radar observations), which complicates and prolongs data acquisition. In most cases, some sort of licensing and non-disclosure agreement is required. In practice, this prevents data sharing, even if the input data used is just a small subset of the full set of obtained data. In some cases, the results of the research can be shared, but without the input data used, such that it is difficult to achieve comparability and reproducibility. Sometimes, non-disclosure agreements are linked to confidentiality/privacy issues, but this could be resolved through anonymisation, or even non-disclosure clauses.

- One solution to the data availability bottleneck may be the **creation of a framework to share ATM-relevant data (including MET data)**, to afford easier access without having multiple agreements in place. This would require the provision of centralised licencing for certain commercial data (and/or the creation of synthetic datasets for the ATM community). Any such activity should be coordinated with EUROCONTROL, and considered in conjunction with its R&D data archive. Centralised commercial data licencing, e.g. across the SESAR 3 ER programme, could be a very effective and time-saving device for researchers, although likely to present several challenges in implementation.
- **Synthetic training data for ML models.** Synthetic data is a particular issue for ML models. These require large datasets for training, testing and validation. In many instances, existing datasets are insufficient to satisfy this data hunger, especially when rare events, such as air traffic conflicts are studied. An additional problem lies in the fact that often real-life (or simulated) data are not clean. Identifying conflict geometries based on aircraft positions derived from SSR or ADS-B data is hindered by the fact that flight planning, flow restrictions and ATC interventions have already eliminated the overwhelming majority of conflicts, the very object of observation. For these and other reasons, the use of artificial datasets for the training of machine learning systems holds some promise, especially since datasets of almost unlimited size may be produced. Different ways of generating such artificial training datasets may be imagined, including cloning, rotating existing data, introducing white noise or generating traffic data with fast-time simulators. Admittedly, these methods have their specific risks as the data so generated differ from 'real' observations in a systematic or stochastic way, which may lead to a bias or lower statistical power due to 'noisy' data. Approaches regarding how to augment the dataset for the training of ML systems and guidelines for understanding the benefits and disadvantages of the different approaches would be useful.
- **Common European Mobility Data Space**. It is also worth flagging in this context the joint initiative of DG MOVE and DG CNECT, regarding the Common European Mobility Data Space. This initiative aims at unlocking the potential of mobility data for both passengers and cargo. The goal is to create a common European data space for mobility, that would "facilitate access, pooling and sharing of transport and mobility data, building on existing and future initiatives" [118]. Current mobility data sharing initiatives, gaps, overlaps and potential common building blocks should be identified, so that the mobility data can be accessed and shared in a secure and controlled way, as outlined in sectoral and horizontal data-related legislation. The Common European Mobility Data Space will also have an impact on air traffic mobility data management, and could open up new research, mobility and business possibilities.

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Community collaboration. Throughout all the workshops, the need for, and benefits of collaborations (on different topics) continued to appear. The topics of collaboration identified in various TCs include:

- There is much interest to get involved in, and create, a **SESAR cybersecurity community**. This interest should be nurtured and used to maintain the good momentum for the cybersecurity community, as there is a risk of losing this momentum in the transition from SESAR 2020 to SESAR 3. The Engage wiki forum on cybersecurity might be one of the tools to bridge this transition gap between the two programmes.
- **Performance assessment and metric development** within various topics and domains, such as trajectory prediction (e.g. on efficiency), or environmental (climate)) impacts, require further development. This would need agreement with all the stakeholders in order to find common approaches and show the benefits of new methods and approaches. A dedicated community spanning ER and IR research would be particularly appropriate in this context, thus building links between the SESAR Performance Framework development and Exploratory Research.
- Climate change issues are somewhat less represented in the SESAR programme when compared to wider European research. Climate change research topics and measurements rely not only on CO_2, but also non-CO_2 impacts. Further, it is important to understand how to assess climate change impact (e.g. aggregation of impacts at the regional level), and how to then incentivise inclusion of such measurement and assessment in operations (e.g. through climate impact regulations). This could also form the basis of a dedicated community for collaboration across disciplines.

Catalyst fund projects

Lessons learned from the perspective of the catalyst fund projects were reported in the individual final technical reports (see catalyst fund project summaries and reporting page and also published as D4.1-D4.18), with Engage's broader lessons learned were reported in D3.10. CF final technical reports were assessed by Engage and found to be of a very high standard – this arrangement has a very low impact on S3JU.

The key points from the CF project perspective (based on project feedback) include:

- The catalyst fund framework allowed flexibility in a relatively low risk budgetary environment (€60k maximum budget allowed through the Horizon 2020 'cascade' funding mechanism); this approach was very well received by all the CF projects, for a variety of reasons. Most obviously, it overcame the commonly-faced barrier for such activity whereby other funding schemes were not available, or set at too high an access bar (e.g. larger projects let through SESAR 2020 ER Calls).
- The 'light touch' reporting requirements were considered to impose a very low administrative burden, which was suited to the budget size and the time available for the projects; the low administrative burden was appreciated as it cut unnecessary overheads and left enough room for the research teams to focus on the actual research. Furthermore, the administrative and mentoring support offered by the Engage consortium was greatly appreciated.
- The Engage reporting templates could have been shared with the projects from the start of the project, thus making reporting requirements known and transparent from the beginning, further lowering the already minimal administrative burden.

The key points from the Engage consortium's perspective include:

- Setting up 18 legal contracts and invoicing processes was a complex task; the batched nature of multiple progress assessment sometimes caused a few delays.
- The CF framework attracted a high level of Industry collaboration, as evidenced through their contributions at the TC workshops (often alongside larger projects), and indeed through their formal reporting.
- The consortium found working with the 18 project teams a very positive experience. A remarkable level of technical outputs was achieved by very many of the projects, particularly considering such relatively limited resources, delivering very high value for money.

PhDs

The consortium found managing the Engage PhD programme to be a highly rewarding activity, that was somewhat burdened with the administrative and bureaucratic requirements of dealing with multiple institutions, with differing systems and rules. Lessons learned related to the PhDs were reported confidentially to the S3JU, however some key points include:

- As with the CF projects, setting up ten legal contracts and subsequent contract addenda were time-consuming tasks. The invoicing process sometimes became a complex activity, with different procedures to deal with among host institutions when making periodic payments.
- Further ad hoc budgetary support that PhD teams could apply for was well received and supported open access publication costs, occasional equipment purchases, travel costs, etc.
- A short PhD progress reporting window is recommended. Engage PhD progress reporting windows opened after each six-month reporting period had been reached and lasted 60 days (as per typical Horizon 2020 reporting windows). However, some progress reporting cycles became delayed, compounded by the need to allow Engage assessors a month to review each progress report and then further time was needed for possible assessment clarifications from the PhD teams.

Workshops

Lessons learned related to the thematic challenge workshops were reported in D2.5, D2.6 and D2.7; the most recent key points include:

- Organising virtual workshops naturally reduced the degree of personal interactions that are otherwise enabled through face-to-face meetings, whilst, in contrast, it generally allows higher participation from both presenters and delegates, since the additional constraints of travel are removed. Nevertheless, there was some reporting of user 'saturation' with such virtual events in general, the number of which has grown over the past 18 months, and this may contribute to some attrition in numbers going forward, such that these types of event need to genuinely offer and communicate something new and of value to participants, it is suggested, in order to maintain reasonably healthy participation numbers.
- A duration for virtual workshops of between half- and three-quarters of a day, ensuring sufficient screen breaks. One day for face-to-face workshops, ideally allowing for a day trip.

Where thematically sensible, co-locating with another event worked well and can help to drive up attendance and range of participation at both.

- Loading workshops with too many presentations is not inspiring for participants; it is better to have a smaller number of presentations, which are well aligned with clear objectives of the workshop, and referring participants to further material, as and when required. More discussion time was often requested by participants.

Summer schools

Lessons learned related to the three summer schools were reported in D5.12, D5.13 and D5.14; the most recent key points include:

- The virtual format worked well given the circumstances. However, a great deal of the feedback received clearly suggests that a physical event is still preferred to the virtual one, and that networking and physical interaction are highly valued elements of events of this kind.
- Although primarily aimed at Engage PhDs, the programme proved to be attractive to other PhD/MSc students and junior researchers, as well as to a number of industry participants.
- The involvement of industry experts to present relevant topics and discuss PhDs' academic research and results was highly appreciated from both perspectives, and substantially contributed to the quality and attractiveness of the summer school. Contacts were established between Engage PhD students and relevant industry experts.

SESAR Innovation Days

Lessons learned related to supporting the SIDs were reported in D2.8, D2.9, D2.19 and D2.11; the most recent key points include:

- The decision to host the 10th and 11th editions of the SESAR Innovation Days on a virtual platform was borne out of the constraints imposed by Covid-19, and 2020 and 2021 offered great learning for everybody involved. As with workshops and summer schools, it is certain that physical events are preferable for a variety of reasons, including the ability to concentrate more fully on the scientific presentations and discussions and the opportunity to network face-to-face.
- Virtual conferencing has upsides, offering greater accessibility. A major benefit being that the number of participants is only limited by the platform licence plus there is flexibility to set up virtual sessions (rather easier than attempting to book meeting rooms at a physical conference). Further advantages include the possibility of reaching out to other international communities; attracting keynote speakers of such a standing that might be difficult to persuade to travel to attend in person.
- In order to further strengthen the visibility of scientific contributions to the SIDs, a Special Issue in a scientific journal should be considered (similar to the 2019 SIDs which culminated in a Special Issue in Elsevier's Journal of Air Transport Management).

EngageWiki

Lessons learned related to the EngageWiki were reported in D3.9; the key points include:

- Extended periods of time were needed to complete the task of sourcing and preparing materials, to resolve underlying data provision issues (e.g. resolving initial legal constraints on accessing SESAR 1 deliverables). The preparation of corresponding metadata was largely a manual task and GDPR affected how information from the wiki tools could be displayed (e.g. ensuring the removal of personal names from keywords) as well as the publication of deliverables in the wiki's repository. This took up a huge amount of effort and resources for the Engage consortium in particular, and for S3JU colleagues in support.
- A number of issues relating to processing the (SESAR) PDF documents. These variously related to header, footer, cover pages, font formats, text information in images, proper names being mistaken as keywords by automated tools, and lists of references placed through the deliverable content, rather than at the end of deliverables. Future work, in SESAR 3, could define an improved reporting format, including systematic key word indexing, to achieve a compromise between convenience of reporting and automated analyses, with a shift more towards the latter, thus better enabling future analyses, similar to those carried out by Engage.
- From the beginning, the wiki was created with the aim of having an active user base. The idea was not only to have a set of tools and a repository, but also to host an active community. This has been one of the most difficult tasks the Engage team has encountered. Getting an active on-line community up and running is very difficult and, in the case of widespread fora such as Quora or StackExchange, can take years. This 'cold start' is often a problem in these types of on-line communities and even more so in niche communities such as ATM. To try to solve this problem, special efforts were made to advertise the wiki in different events (e.g. SIDs, workshops, and summer schools), along with the production of a series of introductory/promotional videos on the wiki landing page in 2022.

4.3 Plan for next R&D phase (Next steps)

The final Engage activities in 2022 will contribute to the legacy of the KTN, through inspiring new researchers and helping to align exploratory and industrial research.

D3.9 and D3.10 comprise a pair of legacy deliverables that the consortium considers will be of particular use and importance for any KTN launched within the SESAR 3 Exploratory Research programme:

- **D3.9 The Engage wiki - an update on the KTN's knowledge hub functionality, research maps and repository**: this deliverable summarises the key features developed, their status and the legacy planning for the wiki;
- **D3.10 Research and innovation insights**: this deliverable highlights future research opportunities for ATM.

5 References

5.1 Project Deliverables

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Appendix A

A.1 Acronyms and Terminology

Table 19: Acronyms and technology

Term	Definition
AAS	Airspace Architecture Study
ADS-B	Automatic dependent surveillance – broadcast
ADSP	ATM Data Services Provider
AI	Artificial intelligence
ANSP	Air navigation service provider
ATCO	Air traffic controller
ATM	Air traffic management
CF	Catalyst fund project
CNS	Communication navigation surveillance
DCB	Demand capacity balancing
EACCC	European Aviation Crisis Coordination Cell
ER	Exploratory research
FPRR	Final Project Results Report
GDPR	General Data Protection Regulation
IR	Industrial research
KPA	Key performance area
KPI	Key performance indicator
MaaS	Mobility as a Service
MET	Aviation meteorology
ML	Machine learning
OTA	Online travel agency
R&I	Research and innovation

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S3JU	SESAR 3 Joint Undertaking (Agency of the European Commission)
SAF	Sustainable aviation fuel
SDA	SESAR Digital Academy
SES	Single European Sky
SESAR	Single European Sky ATM Research Programme
SIDs	SESAR Innovation Days
SRIA	Strategic Research and Innovation Agenda
SSR	Secondary surveillance radar
SWIM	System wide information management
TBS	Time-based separation
TC	Thematic challenge
TP	Trajectory prediction
TRL	Technology readiness level
UAM	Urban air mobility
UAS	Unmanned aircraft system
UDPP	User Driven Prioritisation Process
USSP	U-space service provider
UTM	UAS traffic management
VFR	Visual flight rules
VLL	Very low level

Appendix B

B.1 Engage PhD abstracts

These are the final abstracts, updated by the PhD candidates in 2022. These have also been published along with the PhD final reports on the Engage website (https://engagektn.com/phd-abstracts/).

PhD 1. Decision support system for airline operation control hub centre ('DiSpAtCH')

The general objective of DiSpAtCH (Decision Support System for Airline Operation Control Hub Centre) is to elaborate on artificial intelligence technologies and how these technologies could efficiently support decision making in an Airline Operation Control Hub Centre (OCC) in unexpected or very complex situations.

The daily operation of airlines is often disrupted by unplanned events. As an airline it is therefore essential to operate an OCC to be able to react and mitigate any consequences from the initial disruption. The most challenging task is the information management task. This task includes monitoring, recognition and projection of relevant information out of all information available including current and future situations.

Today the decision making process mainly relies on the experience of the staff working in the OCC. Like in other industries, the desire of using Decision Support Tools (DST) based on machine learning (ML) algorithms is also increasing in the aviation industry. ML algorithms, like neural networks, need a large amount of data to be trained with. The focus of DiSpAtCH is to develop a DST which aims to help the staff in an OCC during disrupted situations. Therefore, three ML modules have been defined of which one aims to propose a suitable action/solution in a disrupted situation. To train the algorithm a database including information about disruptions as well as the implemented solutions from past disrupted situations is needed. Since these kinds of data are not available to researchers and often not recorded by airlines themselves, an approach was needed to get some data to start training algorithms and to validate that certain DST can be developed and support the disruption management process within an OCC. With a decision support system like DiSpAtCH the decisions within an OCC can be optimized which will result in fewer overall disruption cost.

DiSpAtCH provides an approach of using an airline simulation to generate generic operational data of an airline and its daily operations. Synthetic data are generated and ML algorithms are trained to predict actions/solutions for disrupted situations. A first validation shows that a four step classification process including two neural networks can be used to predict actions/solutions in disrupted situations with an accuracy of around 95% and therefore reduce the overall disruption cost by 61% compared to randomly selected actions/solutions.

PhD 2. Trajectory planning for conflict-free trajectories: a multi agent reinforcement learning approach

The objective of this Engage KTN PhD study is to explore and present state of the art AI/ML algorithms towards planning conflict-free trajectories in computationally efficient ways, for a large number of trajectories in airspaces comprising multiple FIRs, following a methodology combining data-driven and agent-based approaches.

In the context of this study the conflicts-free trajectory planning task is defined to incorporate trajectory prediction and conflicts detection and resolution. While trajectory prediction concerns predicting the spatiotemporal evolution of the aircraft state along a trajectory (also called, trajectory evolution), conflicts detection and resolution concerns the detection of conflicts that breach separation minima (loss of separation) between flights and their resolution by appropriate actions. Therefore, the objective of the conflicts-free trajectory planning task is to predict the evolution of trajectories, and regulating flights to avoid loss of separation.

While trajectory planning may take place at the pre-tactical phase of operations, we expect the methods developed in this study to have a large impact in the tactical phase of operations.

Aiming to model stakeholders' decisions to planning conflict-free trajectories, the major emphasis of this study is to imitate flights' trajectories and air traffic controller's behavior according to demonstrations provided by historical data.

The challenges that this study addressed are as follows:

1. Plan trajectories, considering complex ATM phenomena and operational constraints regarding traffic and conflicts among trajectories.

2. Follow a data-driven approach to learn stakeholders' preferences on the evolution of trajectories and on resolving conflicts: stakeholders include airspace users (for trajectory prediction) and air traffic controllers (for conflicts' detection and resolution actions).

3. Address optimization in trajectory planning w.r.t. multiple objectives, preferences and constraints of stakeholders involved, as these are demonstrated by historical data.

4. Address scalability: demonstrate the efficiency of the methods to be applied in settings with a large number of flights.

Contributions that this study makes are as follows:

1. The problem of modelling air traffic controllers' behavior has been split into two well-defined problems: modelling air traffic controllers' reactions on whether and when conflicts' resolution actions should be applied, and modelling air traffic controllers' reactions on how conflicts should be resolved, i.e. what resolution actions should be applied.

2. The problem of trajectory planning (either with or without considering conflicts) has been formulated as an imitation learning problem, based on historical flown trajectories.

3. AI/ML methods have been developed and tested on learning models regarding the evolution of 4D trajectories, using data-driven approaches, i.e. based on historical real-world data.

4. AI/ML methods have been developed and tested on learning models regarding air traffic controllers' reactions and policy using data-driven approaches, i.e. based on historical real-world data.

5. This study has proposed an elaborated evaluation method for data-driven imitation learning techniques predicting air traffic controllers' reactions, considering the uncertainties involved in the evolution of trajectories, in the assessment of conflicts, and in the reactions of ATCO.

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6. Challenging issues due to inherent data limitations have been addressed and thoroughly discussed.

7. The study provides an integrated trajectory planning approach, where data-driven trajectory predictions are intertwined with data-driven conflicts detection and resolution.

PhD 3. Detection, classification, identification and mitigation of GNSS signal degradations by means of machine learning

Among the navigation means, Global Navigation Satellites Systems (GNSS), and namely the Global Positioning System (GPS), have become essential and the availability of a GNSS navigation solution on board seems completely natural. However, the quality of the position calculated by the on-board equipment may be reduced when the received signal is degraded. This degradation can find its origin in a defect of the signal generation system, carried by the satellite, or in the receiving conditions, typically when interferences or multipaths are in addition to the desired signal.

The objectives of the thesis were to detect, classify, identify and finally reduce the impairments of the GNSS signals seen by the on-board receiver, by means of Machine Learning techniques.

More specifically, the performance of Machine Learning methods has been assessed on the signal at the correlator output, the correlator output in short. Indeed, the correlator output is a key element in the calculation of the aircraft's position by the receiver, and, consequently, it is the link in the signal processing chain where the degradations have the most significant impact.

Correlations of the received signal with a local replica over a (Doppler shift, propagation delay)-grid are mapped into grayscale 2D images. They depict the received information possibly contaminated by multipath propagation. The images feed a Convolutional Neural Network (CNN) for automatic feature construction and multipath pattern detection.

The issue of unavailability of a large amount of supervised data required for CNN training has been overcome by the development of a synthetic data generator. It implements a well-established and documented theoretical model. A comparison of synthetic data with real samples is proposed.

The complete framework is tested for various signal characteristics and algorithm parameters. The prediction accuracy does not fall below 93% for Carrier-to-Noise ratio (C/N0) as low as 36 dBHz, corresponding to poor receiving conditions. In addition, the model turns out to be robust to the reduction of image resolution.

PhD 4. Machine learning for aircraft trajectory prediction: a solution for pre-tactical air traffic flow and capacity management

The goal of air traffic flow and capacity management (ATFCM) is to ensure that airport and airspace capacity meet traffic demand while optimising traffic flows to avoid exceeding the available capacity when it cannot be further increased. In Europe, ATFCM is handled by EUROCONTROL, in its role of Network Manager (NM), and comprises three phases: strategic, pre-tactical, and tactical. This thesis is focused on the pre-tactical phase, which covers the six days prior to the day of operations.

During the pre-tactical phase, few or no flight plans (FPLs) have been filed by airspace users (AUs) and the only flight information available to the NM are the so-called flight intentions (FIs), consisting mainly of flight schedules. Trajectory information becomes available only when the AUs send their FPLs. This information is required to ensure a correct allocation of resources in coordination with air navigation service providers (ANSPs). To forecast FPLs before they are filed by the AUs, the NM relies on the PREDICT tool, which generates traffic forecasts for the whole European Civil Aviation Conference (ECAC) area according to the trajectories chosen by the same or similar flights in the recent past, without taking advantage of the information on AU choices encoded in historical data.

The goal of the present PhD thesis is to develop a solution for pre-tactical traffic forecast that improves the predictive performance of the PREDICT tool while being able to cope with the entire set of flights in the ECAC network in a computationally efficient manner. To this end, trajectory forecasting approaches based on machine learning models trained on historical data have been explored, evaluating their predictive performance.

In the application of machine learning techniques to demand trajectory prediction, three fundamental methodological choices have to be made: (i) approach to trajectory clustering, which is used to group similar trajectories in order to simplify the trajectory prediction problem; (ii) model formulation; and (iii) model training approach. The contribution of this PhD thesis to the state of the-art lies in the first two areas. First, we have developed a novel route clustering technique based on the area comprised between two routes that reduces the required computational time and increases the scalability with respect to other clustering techniques described in the literature. Second, we have developed, tested and evaluated two new modelling approaches for route prediction. The first approach consists in building and training an independent machine learning model for each origin-destination (OD) pair in the network, taking as inputs different variables available from FIs plus other variables related to weather and to the number of regulations. This approach improves the performance of the PREDICT model, but it also has an important limitation: it does not consider changes in the route availability, thus being unable to predict routes not available in the training data and sometimes predicting routes that are not compatible with the airspace structure. The second approach is an airline-based approach, which consists in building and training a model for each airline. The limitations of the first model are overcome by considering as input variables not only the variables available from the FIs and the weather, but also route availability and route characteristics (e.g., route cost, length, etc.).

The airline-based approach yields a significant improvement with respect to PREDICT and to the OD pair-based model, achieving a route prediction accuracy of 0.896 (versus PREDICT's accuracy of 0.828), while being able to deal with the full ECAC network within reasonable computational time. These promising results encourage us to be optimistic about the future implementation of the proposed system.

PhD 5. Deep Multi-Agent Reinforcement Learning Applications in ATM

Air Traffic Management's (ATM) aim is to ensure separation management of aircraft in an efficient way, minimizing possible delays and costs. The expected increase in air traffic demand across manned and unmanned traffic requires a higher level of automation to support the decision making. Adaptive self-Governed aerial Ecosystem by Negotiated Traffic (AGENT) was an exploratory research project supported by the H2020 Research and Innovation Programme, which proposed a system where the avoidance of potential loss of separations is done in a distributed and collaborative way while the controllers monitor the process. This PhD project is built on AGENT's future work proposals and seeks

possible improvement of several critical aspects of the system through the application of Machine Learning (ML) techniques. There were two clear goals in this project: define airspace complexity in a way that challenges current definitions and overcomes their limitations and investigate how ML can be applied to safety in aviation. We investigate these problems in en-route traffic at the tactical level, as well as UAV systems.

The first major contribution of this thesis has been modelling air traffic as a graph in the context of airspace complexity and conflict resolution. We define a graph with aircraft as nodes and interdependencies between them as edges of the graph. This definition allows for problem specific definitions of interdependencies. We further extend the definition of air traffic as a graph by including the time domain, which creates dynamic graphs. We define airspace complexity as graph connectivity and propose four indicators that combine different topological information and the severity of interdependencies to give a complete and nuanced picture of complexity. These indicators are able to provide a dynamic evolution of complexity by leveraging the modelling choice of air traffic as a dynamic graph. Simulation results indicated that the indicators we propose give detailed information and overcome drawbacks of existing metrics. We evaluated our approach using real and synthetic traffic and demonstrated that the indicators express different facets of complexity, confirming that all indicators are needed. The way we define complexity also provides a new framework in the design of conflict resolution algorithms which considers the reduction of airspace complexity in addition to safety preservations. Conflict Resolution (CR) algorithms could be discouraged from providing solutions that increase the overall complexity of the airspace.

Furthermore, we model CR as Multiagent Reinforcement Learning Problem (MARL). We initially investigate CR only in a pairwise setting using Multiagent Deep Deterministic Policy Gradient (MADDPG) as a learning algorithm. We propose a novel state representation that combines positional information with speed and heading of the aircraft. Additionally, we propose a reward function that not only guides agents towards solving the conflict but also to consider factors such as fuel consumption, airspace complexity and delays. Our results indicate that the agents are capable of solving the conflicts and further learning desired behaviours such as solving them as soon as possible with minimal manoeuvres. However, this method suffers from issues of scalability and nonstationarity. In order to overcome these issues, we utilize Graph Neural Networks (GNNs). GNNs inherently allow communication between agents which facilitates cooperation between them. We apply Graph Convolutional Reinforcement Learning (DGN) in CR for Unmanned Aerial Vehicles (UAV) to solve conflicts with 3 and 4 present aircraft which we assume to be cooperative. We achieve impressive performance with the agents being able to always solve the conflicts. Furthermore, they learn a strategy that increases the distance between them, without previous knowledge of the environment. Currently, we are using this application domain to investigate some fundamental questions in MARL such as agent coordination, heterogeneity and transparency in environments where agents have individual and common goals.

PhD 6. Integrating weather prediction models into ATM planning ('IWA')

Weather has a strong impact on ATM. Inefficient weather avoidance procedures and inaccurate prognosis lead to longer aircraft routes and, as a result, to fuel waste and increased negative environmental impact. A better integration of weather information into the operational ATM-system will ultimately improve the overall air traffic safety and efficiency.

Covid-19 pandemics affected aviation severely, resulting in an unprecedented reduction of air traffic, and gave the opportunity to study the flight performance in non-congested scenarios. We discovered noticeable inefficiencies and environmental performance degradation, which persisted despite significant reduction of traffic intensity. The PhD thesis proposes a methodology that allows us to distinguish which factors have the highest impact on which aspects of arrival performance in horizontal and vertical dimensions.

Academic Excellence in ATM and UTM Research (AEAR) group operating within the Communications and Transport Systems (KTS) division at Linköping University (LIU), together with the Research and Development at Luftfartsverket (LFV, Swedish ANSP) develops optimization techniques to support efficient decision-making for aviation authorities.

In this thesis, we apply probabilistic weather modelling techniques, taking into account the influence of bad weather conditions on the solutions developed in our related projects and integrate them into the corresponding optimization frameworks. First, the PhD student enhanced the optimization framework for arrival route planning in TMA, with the convective weather avoidance technique. Next, the probabilistic weather products were used to obtain an ensemble of staffing solutions, from which the probability distributions of the number of necessary ATCOs were derived. The modelling is based on the techniques recently developed within several SESAR projects addressing weather uncertainty challenges. The proposed solutions were successfully tested using the historical flight data from Stockholm Arlanda airport and five airports in Sweden planned for remote operation in the future.

PhD 7. Advanced statistical signal processing for next generation trajectory prediction

Accurate and reliable trajectory prediction (TP) is required in several air traffic management (ATM) systems, for instance, to design air and ground-based decision support tools and safety nets. Estimating the aircraft trajectory in the vertical plane typically requires the knowledge of a pair of aircraft intents (e.g., constant Mach and minimum throttle), information which is seldom available, besides for the ownship (i.e., one's own aircraft) trajectory planning system. In the flight execution phase, the aircraft is directed by the (auto) pilot through a series of sequential guidance modes that might override some of the planning phase aircraft intents. Thus, guidance mode is defined as a combination of constraints/commands that specify how the aircraft should behave to perform a desired trajectory.

Reliable guidance mode information is fundamental for next generation of air- or ground-based TP, especially in the context of trajectory-based operations (TBO) and advanced decision support tools for aircraft crew and/or air traffic control e.g., to improve conflict detection (and resolution) algorithms, conformance monitoring, departure/arrival managers, separation assurance systems, etc. These new tools might result in increased safety, capacity, predictability and cost-efficiency for the future European ATM system.

This research is concentrated on identifying aircraft guidance modes in the vertical plane. The final goal of this study is to indicate that acquiring the knowledge of aircraft guidance mode significantly affects the TP problem, and subsequently, the new ATM systems. In this PhD i) we provided a new probabilistic perspective of the trajectory prediction problem using signal processing mathematical tools, ii) we review state-of-the-art and the main challenges for the design of novel or enhanced TP systems that should enable future ATM paradigms, iii) we develop an optimal guidance mode identification using a Kalman filtering approach, iv) we analyse the impact of model mismatch on the

interacting multiple model (IMM) filtering technique, v) we propose a robust linear-constrained IMM filtering under model mismatch, vi) we also propose a new methodology based on Bayesian inference to identify the aircraft guidance modes, and finally, vii) we evaluate the methodology to indicate the effect of known guidance modes on the TP accuracy.

PhD 8. A pilot/dispatcher support tool based on the enhanced provision of thunderstorm forecasts considering its inherent uncertainty ('STORMY')

Uncertainties inherent to convective weather constitute a major challenge for the Air Traffic Management System (ATM), affecting its safety, capacity, and efficiency. Specifically, thunderstorms represent an important threat, as they involve phenomena such as strong turbulence, wind shear or hail. It is essential to avoid them to ensure both passenger comfort and aircraft structural integrity. Thunderstorms' location and timing are hard to predict with certainty. This stochasticity is an important element that methodologies for aircraft trajectory planning must take into account.

For this purpose, two different methodologies for flight planning in areas of uncertain thunderstorm development are proposed. Both are heuristic approaches that rely on the iterative manipulation of graphs. Moreover, to enhance computational performance and enable real time operation, they are parallelized by means of GPU programming, producing results in less than seconds.

On one hand, the Scenario-Based Rapidly-Exploring Random Trees (Scenario-Based RRTs or SB-RRTs) are introduced, three algorithms for trajectory planning that explore an airspace with a tree structure. This kind of graph grows from the origin and looks for a connection with the destination through a safe sequence of tree branches. On the other hand, the Augmented Random Search (ARS) is proposed for trajectory deformation. This algorithm is applied to a graph, and it looks for the optimal sequence of edges, its relocation, and the best profile of velocities to minimize a combination of time and fuel.

The methodologies are tested with Ensemble Prediction Systems (EPS) that characterize atmospheric uncertainties through a set of possible forecasts. Results reveal that the algorithms are able to ensure safety and minimize objectives, such as time of flight, flight distance or fuel consumption.

PhD 9. Second generation agent-based modelling for improving APOC operations

The main objective of this work is to create a Decision Support Tool to help the Airport Operation Centre with the integration of different approaches at the macroscopic level to make better decisions to minimize airport congestion by mitigating conflicts of critical resources. The main conflicts are related to different processes of the airport management and the capacity, so, the main problems are related to the minimum separation, runway, taxiway, terminal, gates, and ground handling team capacity (overloads) and availability.

We propose a framework as part of the Decision Support Tool to solve the conflicts addressed, we adapted an optimization with simulated annealing heuristic combined with a time decomposition approach (sliding windows).

As part of the solution, we evaluate the performance of the different modules and how the number of conflicts is solved, the final objective is to improve the coordination and efficiency of the operations of an airport. To validate the optimization model and to show the benefits of the macroscopic

decomposition approach different computational experiments were performed with real data of one day of operations from Paris Charles de Gaulle airport including the parameters of this airport.

PhD 10. Resource-Constrained Airline Ground Operations: Optimizing Schedule Recovery under Uncertainty

Air Traffic Flow Management (ATFM) and airlines use different paradigms for the prioritisation of flights. While ATFM regards each flight as individual entity when it controls sector capacity utilization, airlines evaluate each flight as part of an aircraft rotation, crew pairing and passenger itinerary. As a result, ATFM slot regulations during capacity constraints are poorly coordinated with the resource interdependencies within an airline network, such that the aircraft turnaround – as the connecting element or breaking point between individual flights in an airline schedule – is the major contributor to primary and reactionary delays in Europe.

This dissertation bridges the gap between both paradigms by developing an integrated schedule recovery model that enables airlines to define their optimal flight priorities for schedule disturbances arising from ATFM capacity constraints. These priorities consider constrained airport resources, such as ATFM slots, airport stands or ground handling personnel and different methods are studied how to communicate airline-internal priorities confidentially to external stakeholders for collaborative solutions, such as the assignment of reserve resources or ATFM slot swapping.

The integrated schedule recovery model is an extension of the Resource-Constrained Project Scheduling Problem and integrates aircraft turnaround operations with existing approaches for aircraft, crew and passenger recovery. The model is supposed to provide tactical decision support for airline operations controllers at look-ahead times of more than two hours prior to a scheduled hub bank. System-inherent uncertainties about process deviations and potential future disruptions are incorporated into the optimization via stochastic turnaround process times and the novel concept of stochastic delay cost functions. These functions estimate the costs of delay propagation and derive flight-specific downstream recovery capacities from historical operations data, such that scarce resources at the hub airport can be allocated to the most critical turnarounds.

The model is applied to the case study of a network carrier that aims at minimizing its tactical costs from several disturbance scenarios. The case study analysis reveals that optimal recovery solutions are very sensitive to the type, scope and intensity of a disturbance, such that there is neither a general optimal solution for different types of disturbance nor for disturbances of the same kind. Thus, airlines require a flexible and efficient optimization method, which considers the complex interdependencies among their constrained resources and generates context-specific solutions. To determine the efficiency of such an optimization method, its achieved network resilience should be studied in comparison to current procedures over longer periods of operation.

For the sample of analysed scenarios in this dissertation, it can be concluded that stand reallocation, ramp direct services, quick-turnaround procedures and flight retiming are very efficient recovery options when only a few flights obtain low and medium delays, i.e., 95% of the season. For disturbances which induce high delay into the entire airline network, a full integration of all considered recovery options is required to achieve a substantial reduction of tactical costs. Thereby, especially arrival and departure slot swapping are valuable options for the airline to redistribute its assigned ATFM delays onto those aircraft that have the least critical constraints in their downstream rotations.

The consideration of uncertainties in the downstream airline network reveals that an optimization based on deterministic delay costs may overestimate the tactical costs for the airline. Optimal recovery solutions based on stochastic delay costs differ significantly from the deterministic approach and are observed to result in less passenger rebooking at the hub airport.

Furthermore, the proposed schedule recovery model can define flight priorities and internal slot values for the airline. Results show that the priorities can be communicated confidentially to ATFM by using flight delay margins, while slot values may support future inter-airline slot trading mechanisms.

Co-funded by the European Union

B.2 Engage catalyst fund project abstracts

These are the final CF project abstracts. These have also been published along with the executive summaries and final technical reports on the Engage website (https://engagektn.com/cf-summaries/).

C1. Probabilistic weather avoidance routes for medium-term storm avoidance ('PSA-Met')

PSA-Met integrates new meteorological capabilities in the storm avoidance process, namely, probabilistic nowcasts. These new meteorological products provide not only a forecast of the storm's evolution, but also information about the uncertainty of the convective cells. PSA-Met develops a probabilistic weather-avoidance concept, according to which, the required inputs are a probabilistic nowcast and a risk level, which is an adjustable parameter intended to define the avoidance strategy. The output is a unique avoidance trajectory that takes into account the uncertainty of the convective cells, obtained for the given risk level. Simulation results show that the predictability, the safety and the workload of pilots and air traffic controllers are improved, although with a small loss of flight efficiency. This new weather avoidance concept will be used in a follow-up project, whose objective will be to develop a Medium-Term Storm Avoidance tool intended to enhance air traffic control efficiency.

C2. airport-sCAle seveRe weather nowcastinG project ('CARGO')

This project has combined measurements from different instruments to develop a nowcasting algorithm of extreme weather events in a localised area around the Malpensa airport with the aim of improving aviation safety. Radar reflectivity has been used as reference to define and select the extremes; Global Navigation Satellite System (GNSS) zenith total delay, atmospheric parameters from weather stations, and lightning have been used as inputs of a neural network to predict the development of the weather events in the near future (from 30 to 90 minutes before). The results show an accuracy of 0.75 in nowcasting the extreme events when using all the datasets as inputs and decreasing accuracy when excluding one of the inputs. However, there are still several tests that should be performed to understand the optimal setting of the algorithm. This project was the first experiment to collect so many atmospheric sensors in a localised area to nowcast extreme events with ATM purposes and posed the basis to develop a deeper study on this field.

C3. Authentication and integrity for ADS-B

The main objective of this project is to provide the means to improve the security of the Automatic Dependent Surveillance-Broadcast (ADS-B), a critical backbone of future surveillance systems. More specifically, we evaluate the data link capabilities of the so-called phase overlay, a backwards-compatible extension to the current implementation of ADS-B. Our results indicate that 8PSK performs best in a realistic radio environment, reliably providing up to 218 additional bits for each ADS-B message at a carrier frequency offset tolerance of about 40 kHz. Based on these insights, we propose a protocol that relies on the phase overlay to authenticate the information provided via the ADS-B.

C4. Data-driven trajectory imitation with reinforcement learning

The objective of this project was to present algorithms for data-driven imitation of trajectories, following deep reinforcement learning techniques towards enhancing our trajectory prediction abilities. We aimed at building a data-driven approach in which the learning process is (a) an imitation process, where the algorithm tries to imitate 'expert', demonstrated trajectories, (b) exploiting raw trajectory data, enriched with contextual data (e.g. weather conditions etc) and (c) based on reward models (for producing trajectories in high-fidelity) that are learned during imitation. There are two main project contributions (i) a general framework for the prediction of trajectories in which deep imitation and reinforcement learning methods play a major role, together with methods selecting important features for decision making and future trajectory classification methods; and (ii) a developed and evaluated state of the art deep imitation learning techniques for predicting trajectories in the aviation domain, showing their potential for highly accurate prediction results, especially in long trajectories with multiple patterns / modalities, and in cases where the demonstrated trajectories are few.

C5. A Data-drIven approach for dynamic and Adaptive trajectory PredictiON ('DIAPasON')

The DIAPasON project focuses on the need of the ATM system to develop tools and methodologies which are able to support traffic and trajectory management functions. For these activities, trajectory and traffic prediction is key, in particular within the context of Trajectory-Based Operations (TBO). While previous research exists addressing these matters, DIAPasON presents a different approach. In particular, the project aims at analysing patterns of flight plan evolution for individual flights, and extract patterns and feature which can be applied in a wide number of operational contexts where this information is available. The main result of the project is the development of a methodology for trajectory prediction and traffic forecasting in a pre-tactical phase (from a few days to a few hours before the operations, when a only limited number of flight plans are available). This can be adjusted to different time scales (planning horizons), considering the level of predictability of each of them and the specific use case to where it should be applied. These results have been explored with support of operational staff to maximise the benefits in the pre-tactical phase.

C6. Operational alert Products for ATM via SWIM ('OPAS')

Volcanic emission is a threat to ATM and the safety of flights. Early warnings are an essential source of information for stakeholders. The OPAS project is the development of a SWIM Technical Infrastructure Yellow Profile service providing information (notification & data access) about volcanic SO_2 height. The OPAS service considers observations from three hyperspectral satellite sensors (TROPOMI, IASI-A and IASI-B), respectively operating in the ultraviolet and infrared ranges. These instruments represent the state of the art of satellite SO_2 measurements. The IASI sensor already provides well recognised estimations of SO_2 height, which is available through the SACS early warning system and contributes to the OPAS service. The outcome of the OPAS project is the new algorithmic development (iterative SO_2 optical depth fitting) of TROPOMI SO_2 height retrievals, the creation of alerts and access to tailored information, i.e. SO_2 contamination of flight level and improved mass loading estimates.

C7. An interaction metric for an efficient traffic demand management: requirements for the design of data-driven protection mechanisms ('INTERFACING')

A major limitation of the current ATM system is the loss of effectiveness due to the limited integration between the layered planning Decision Support Tools (DSTs). While the Trajectory Based Operation concept enables new DSTs that could deal with present demand/capacity, a word of caution at a practical level: ATM stakeholders realise that technological flexibility to regulate flights into a sector is not synonymous of performance, rather several negative effects can arise at the network level due to lack of analysis of interdependencies among regulated sectors. INTERFACING has developed a formal probabilistic framework to detect and characterise at the network level the flight interactions and their interdependencies. New interaction metrics have been implemented to enable the evaluation of regulation efficiency and to pave the way for the design of mitigation measures for a smooth fine-tuning of traffic demand at a micro level that considers the effects at a macro level improving the network performance.

C8. MET enhanced ATFCM

The MET Enhanced ATFCM R&D initiative has been launched by MetSafe and France Aviation Civile Services. This one-year project addressed the provision of accurate convection information for ATFCM activities, with the 6 hours' time-horizon as a target. The research approach focused on both technical and operational aspects, as needs identification and concept of operations, assessment of convection models, design and deployment of a model-based R&D convection product. Up-to-date and accurate European thunderstorm forecasts at +6 hours horizon built from a multi weather model algorithm have been delivered as a SWIM webservice for Reims Upper Area Control Centre during technical and operational validation trials. Initial project objectives have been fulfilled: Reims air traffic controllers and FMP operators greatly improved their weather situational awareness and would have been likely to take ATCFM measures based on received information.

C9. Exploring future UDPP concepts through computational behavioural economics

When the demand of an airspace sector is expected to exceed capacity, flights are delayed and assigned new take-off times through ATFM slots. This delay represents a significant cost for airlines and passengers. The possibility of rearranging flight sequences offers remarkable potential to reduce the impact of ATFM delay. Several prioritisation instruments are proposed in the literature, but their implementation is hindered by the limitations of classical modelling approaches to represent Airspace Users (AUs) behaviour and network effects in a realistic manner. The aim of the project is to overcome these limitations through the combined use of agent-based modelling (ABM) and behavioural economics. The model developed by the project has been used to simulate the performance of a variety of flight prioritisation under different network conditions and AU behaviours, allowing the observation of emergent phenomena and opening the way for a rigorous and comprehensive assessment of innovative approaches to User Driven Prioritisation Process (UDPP).

C10. The drone identity - investigating forensic-readiness of U-Space services

The Drone Identity project investigates forensic-readiness requirements of unmanned aerial systems (UAS), to help identify causes of safety and security related air traffic incidents. It is a collaborative effort between researchers at The Open University (OU) and NATS. The project contributes to addressing the vulnerabilities and global security of communications, navigation, and surveillance systems in air traffic management (CNS/ATM). The collection and use of forensic data associated with drones and surrounding physical contexts is key to effective investigation. The research is conducted in the context of U-Space, focusing on the architecture and concept of operations for European unmanned traffic management (UTM), and the ability to preserve such vital information as evidence for forensic investigations. The goals of such forensic readiness are to ensure that the root causes of incidents can always be analysed, facilitated by evidence collected during operation (drone flight). The project focuses on drone data, examining ways in which key drone characteristics can be determined and recorded soundly, if and when incidents involving the drone(s) occur. In particular, the key attributes that characterise and identify the drones, their operators, and their anomalous behaviours will be investigated. A prototype demonstrator has been developed, including a technical architecture, to illustrate and evaluate the proposed forensic readiness requirements for U-Space services.

C11. Proof-of-concept: practical, flexible, affordable pentesting platform for ATM/avionics cybersecurity ('ATM-cybersec')

During the last decade, cybersecurity started to increasingly become an issue because many ATM/ATC/aviation stakeholders rely on electronic systems for critical parts of their operations, including safety-critical functions in avionics and related software/firmware. This project aims at closing this gap by developing a proof-of-concept practical, flexible, affordable pentesting platform for ATM/avionics cybersecurity. For this purpose we have developed from scratch a novel and unique end-to-end early stage (TRL3-4) platform as well as a comprehensive hardware/software testbed. With these, we have performed several hundreds of experimental iterations and developed four novel attacks while implementing altogether more than ten attacks. After pentesting more than 120 cumulative testbed configurations, we have discovered more than 40 vulnerabilities (e.g., Denial-of-Service, crashes, hangs) and a handful of logical and implementation bugs, all these posing imminent, realistic and dangerous cyber-physical threats to safe aviation/ATM/ATC. We also successfully re-purposed our platform for defensive mechanisms, such as 'RSS-Distance' model for detecting fake/spoofed ADS-B messages. Our methodologies and results are thoroughly documented in three distinct research manuscripts that currently undergo academic peer-review.

C12. Safe drone flight - assuring telemetry data integrity in U-Space scenarios ('SDF')

The Safe Drone Flight ('SDF') project was led by NATS in collaboration with The Open University (OU) and funded by the SESAR Engage Knowledge Transfer Network (KTN) catalyst. The project investigated the security of unmanned flight surveillance systems and, in particular, the drone telemetry data they transmit. Developing a safety assured and cyber secure surveillance system is an important step in enabling U-space services, supporting safe, efficient and secure access to airspace for large numbers of drones. This project matured a prototype blockchain-based drone surveillance system taking a U-space scenario-based approach to simulate several drone operations and validate the concept's

suitability. Cyber security and safety assurance related research was conducted to determine data integrity-related design and performance requirements on the solution respectively.

C13. Flight centric ATC with airstreams ('FC2A')

The project addresses a challenging approach for an environmentally friendly and more agile ATM framework by combining a Flight Centric ATC (FCA) approach and the Airstream concept. The day-to-day adaptation of the Airstream network to the demand of the airspace users will provide a resilient and scalable system for supporting Dynamic Airspace Configuration (DAC). Driven by the digitalisation of ATM, autonomous management of aircraft inside the Airstream is promoted. A computational framework is implemented for the evaluation of the concept. New aggregation methodologies are proposed for extracting main traffic flows (aggregated flights) from the initial demand. A simple mechanism for building the tri-dimensional structure of the Airstream network and flight allocation is then applied using the aggregation results. New trajectories of the Airstream network traffic are ultimately produced. Finally, comparison of the various traffic samples (i.e. original versus airstream) is performed through complexity evaluation. The metrics used, based on geometric information approach, have been improved for large spherical areas.

C14. Meteo Sensors In the Sky ('METSIS')

The Meteo Sensors in the Sky (METSIS) project explores the use of drones as a wind sensor network for U-space applications. The novel concept aims to provide accurate and low-cost wind nowcasts for drones using data collected by drones themselves, i.e., 'wind nowcasts for drones by drones'. A proof-of-concept flight-test experiment was performed using four drones to determine the feasibility of the METSIS concept at low altitudes. In the current incarnation, ultrasonic anemometers were mounted to each drone to measure local winds. The flight-tests evaluated the effect of obstacle-induced wind distortion, drone motion, measurement density, and measurement errors. Additionally, wind fields estimated during the flight-tests were published in real-time to the AirHub Drone Operations Center – a functional U-space Service Provider – to demonstrate the communication of these data to real end-users. The results indicate that the METSIS concept is a promising solution for wind nowcast component of the U-space weather information service. Future research should investigate the accuracy of the concept for a wider range of scenarios than considered here, and develop the technologies needed to increase the scalability of the concept.

C15. Probabilistic information Integration in Uncertain data processing for Trajectory Prediction ('PIU4TP')

The objective of the PIU4TP project is the development of a data-driven methodology for the trajectory prediction from long to short term before scheduled time of flight. Specifically, the methodology uses machine learning and data mining techniques to perform data analysis and to learn from past experience the aircraft future behaviour in terms of flight path selection. Therefore, it exploits historical data and uncertainties of current forecasts of some relevant mission and aircraft parameters to compute trajectory prediction outcomes enriched with associated probabilistic information. The project's final aim is to build a methodology that can support the Network Manager with air traffic flow and capacity management, allowing the optimisation of flight distribution among sectors and

flight routes, the anticipation of air traffic flow requests and the identification in advance of potential conflicts.

C16. Collaborative cyber security management framework

To support the safety of the ATM system, the future ATM architecture needs to deliver an exceptionally high level of cyber security. The objective of this project was therefore to advance cyber security management in several directions: (a) to develop a more collaborative approach to cyber security management; (b) to prototype these collaborative approaches; and (c) to adapt SESAR's existing risk assessment methodology, 'SecRAM', to more quantitative methods, from which Bayesian Network analysis could be applied. The outputs of the project were a concept of operations for collaborative security management, a basic prototype for collaborative security management, and an approach for the application of Bayesian Networks. The prototype was developed to support a risk assessment that could be done in collaboration between several partners, such as by the members of a SESAR Solution Project. The outcome of the project is a step forward in information sharing, productivity and methods of knowledge exchange in cyber security.

C17. Role of Markets in AAS Deployment ('RoMiAD')

Virtualisation provides a path for air navigation service providers (ANSPs) to address the implementation of the open architecture proposed by the Airspace Architecture Study (AAS). Project RoMiAD has developed an understanding of the high-level benefits of deploying the distributed architecture proposed by the AAS and potential mechanisms to incentivise the organisational reengineering necessary to achieve a Digital European Sky whilst ensuring national sovereignty over airspace. During the course of Project RoMiAD, it has become clear that if virtualisation had been adopted before 2018 across Europe – ATM costs could have been 30% cheaper and there would have been no significant en-route delay – only unremovable delay would have remained e.g. caused by weather. 75% of the benefits come from improvements in the air traffic services (ATS) layer – increasing Air Traffic Controller Officer (ATCO) productivity and capacity sharing – and are best enabled by the flexibility that the common data layer provides. The focus to achieve the benefits needs to be on building alliances and collaborations within the ATS layer to ensure that the common data layer can support those collaborations.

C18. Weather impact prediction for ATFCM ('WIPA')

The WIPA – Weather Impact Prediction Tool for ATFCM initiative – has been launched by MetSafe and France Aviation Civile Services, in collaboration with Reims and Marseille Upper Area Control Centres. This one-year project addressed how the provision of weather hazards impact information on air traffic control sectors in intervals of one hour over the ATFCM horizon. To do so, WIPA considered the convection information as an input provided by the MET Enhanced ATFCM product (developed during the first catalyst wave), additional MET information (as real-time convection observation and SIGMET), and ATM information. The research approach focused on both technical and operational aspects, as needs identification, design of the tool and deployment via a SWIM webservice. Technical and operational validation trials showed that initial project objectives have been fulfilled: Reims and

Marseille ATCOs and FMP operators highly improved their weather situational awareness and would likely have taken ATCFM measures based on received information.

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B.3 Gap analysis: projects least connected with the SRIA

The gap analysis commentary in Section 2.4 refers to the following table.

To recap, as the final result of the gap analysis, a semantic similarity index was obtained for each of the projects being analysed with respect to the descriptions of the nine SRIA flagship activities, and the least overall connected to the SRIA are ranked in the following table. The first column is the ranked weakest link (i.e. least-connected first), although undue importance should not be ascribed to differences between specific rankings. As a further, crude validation exercise, three keywords were manually assigned to each of the projects, and searched in the SRIA, to check that none of the projects had an apparently very strong representation in the latter. In most (14) of the cases (projects), the total (of three) keyword hits was zero or one. The highest, rather counter to the ranking, was the occurrence of "training" (indicated by project 1), 14 times in the SRIA. The text samples (right-hand column) were normally taken from the projects' final reports and are unedited. For further information on them, the reader is referred to the Engage research repository [60].

Table 20: 20 projects least connected with the SRIA

Project / rank	WBS	Acronym	Title	Text samples
1	16.04	-	Human Performance Management System R&D	Project 16.04 was concerned with the overall management and coordination of the 16.04.0x projects that were responsible for the SESAR ATM Human Performance Management System R&D activities. This R&D covered four areas: • 16.04.01 Evolution from ATM HF Case to a HP Case Methodology for SESAR • 16.04.02 HP Tool Repository of SESAR Standard HP Methods and Tools • 16.04.03 Impacts of Future Systems and Procedures on Selection, Training, Competence and Staffing Requirements • 16.04.04 Social and Cultural Factors impacting on SESAR Changes All these projects have now completed and have delivered their final deliverables. As explained in section 3.8 of the ATM Master Plan (Edn 2), the human element remains pivotal to the success of SESAR, and also that the concepts being developed within SESAR must take account of human strengths and weaknesses in their development. The deliverables of the 16.04.0x projects provide the guidance necessary for SESAR R&D projects to take account of the human aspects when developing SESAR concepts, and therefore these deliverables are essential to facilitating the ultimate deployment of the ATM master plan roadmap.
2	16.01.03	-	Develop techniques for Dynamic Risk Modelling	The objectives and achievements of the project are summarized as follows: • Demonstrate the added value of DRM with respect to static risk modelling ○ Achieved and documented in Deliverable "D09" Dynamic Risk Modelling SESAR test case application and lessons learned. This comprehensive report includes all steps and results of DRM application. Agent-based DRM has been shown to be workable and useful for ATM applications. • Produce a guideline for *when* and *how* to apply DRM techniques in real world analysis

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Project / rank	WBS	Acronym	Title	Text samples
				○ Achieved and document. through iterative approach from initial guidelines until final The result was coordinated with P16.06.01 that addresses the SESAR Safety Reference Material and its application.
3	12.07.03	-	Airport Performance Assessment and Management Support Systems	The main objective of the Primary Project "Airport Performance Management Assessment and Management Support Systems" (APAMS) was to specify, develop and verify the AirPort Operation Centre (APOC) support tool, which is able to collect and evaluate information from the Airport Operations Plan (AOP), allowing monitoring and management of the airport´s performance by providing mechanisms to the APOC stakeholders to resolve any unexpected operational disruptions in a collaborative manner.
4	12.06.07	-	AMAN, SMAN, and DMAN fully integrated into CDM processes	The scope of this project was to define, develop and validate the operational concept related to integration of A-SMGCS, AMAN and DMAN services in the Collaborative Decision Making process. The objective of the integration was to support the controller to optimise the traffic flow at the airport exploiting the following functionalities: - managing the traffic flow at the airport, - optimising the runway occupancy, - minimising the taxi-time, - avoiding conflict situation
5	12.02.01	-	Runway Management Tools	The technical project "Runway Management Tools" was focused on the specification, development and verification of a prototype based on the Runway Demand and Capacity Balancing operational concept. Since the beginning, the objectives of this project were to: • Provide in advance the optimal runway configuration according to the factors affecting the runway (weather, infrastructure, maintenance…) that will enable to accommodate the expected demand while reducing delays. • Monitor and manage the configurations proposed identifying any possible imbalance to take corrective actions. • Calculate the available capacity and provide capacity forecasts for the following hours to optimize runway throughput. • Assist the Tower Supervisor with decision support tools in managing and optimizing the runway configurations according to the arrival and departure demand during short term and execution phase by using what-if mode. • Notify any imbalance detected to external systems such as queue distributors (Arrival and Departure Managers) or Airport Operations Plan (AOP), in order to take appropriate actions To achieve these objectives a stepwise approach in two phases was agreed according to the maturity of the operational concept, the stakeholders involved in the project were assigned to project tasks according to their expertise.

Project / rank	WBS	Acronym	Title	Text samples
6	12.06.02	-	The Airport Operations Plan (AOP), decision support tools and conflict detection tools to be integrated in APOC for managing the overall performance of the Airport	The main objective of this project, named "The Airport Operations Plan (AOP), decision support tools and conflict detection tools to be integrated in APOC for managing the overall performance of the airport", was to specify, develop and verify an AOP prototype which is able to monitor aircraft and passenger processes at the airport and display them to the user as an Airport Transit View (ATV), in order to enhance the performance both at the airport and across the Network.
7	12.05.04	-	Integrated Tower Working Position (CWP) Design, Specification Prototyping and Test/Validation	This project has been focussed on the definition, development and verification of an Advanced Tower Controller Working Position (A-CWP) that continuously provides an airport situation display to the tower controllers. The technical project "Integrated Tower Working Position (A-CWP) Design, Specification Prototyping and Test/Validation" was the main technical project in the Airport domain for the definition, development, verification and support to integrated validations of a homogeneous human-machine interface (HMI) of the different concepts defined in SESAR1.
8	09.05	ASAS-ASPA	ASAS-ASPA	This document synthesises the work performed in SESAR project 09.05.00 in charge of defining, validating and implementing two airborne functions: • One allowing the aircraft to execute time-based spacing instructions; • The other providing an improved situational awareness to flight crews whenever operating visual operations. The SESAR 09.05 ASAS-ASPA project was in charge of defining, implementing and validating two airborne functions: • One function allowing the aircraft to execute time-based spacing instructions given by the controller, with the objective to reach pre-industrial development level (TRL6) • The other function providing an improved situational awareness to flight crews whenever they operate visual operations relatively to a traffic, with the objective to propose a first iteration of an avionics solution (TRL3)
9	12.03.02	-	Enhanced Surface Safety Nets	In reference to the ATM (Air Traffic Management) Master Plan, the project 12.03.02 aimed at improving Surface Safety Nets functions for controllers providing better and safer surface traffic management and operations on the airport. The partners focused on defining the requirements and prototypes for the following functionalities: • Runway Incursion • Area Intrusion • Conformance Monitoring Alerts for Controllers (CMAC) • Conflicting ATC Clearances (CATC)
10	06.03.01	-	The Airport in the ATM environment	The project 06.03.01 addressed the Airport Operations Management and Surface Management domains. For the Airport Operations Management domain, the main objective of the project was to develop and validate the SESAR concept. The project was responsible for further validating the concept at the V2 maturity level as well as concluding the V3 activities. Finally, the project was responsible for the delivery of the final Airport Operations Management documentation and was also responsible for

Project / rank	WBS	Acronym	Title	Text samples
				a number of tasks which were performed in order to prepare the future research work. For the Surface Management domain, the project performed Real-Time simulations and Live trials/Shadow mode trials to assess the level of maturity reached by validated SESAR solutions and to provide validation results for the final production of the concept documents.
11	16.04.01	-	Evolution from the ATM HF Case to a HP Case Methodology for SESAR	The aim of P16.04.01 was to develop a HP assessment process for SESAR that serves to ensure HP aspects are systematically identified and considered in the SESAR operational and technical concept developments for both ground based and air-borne projects, i.e. WP 4-15. The HP assessment process developed for SESAR had to be compatible with the validation approach adopted within SESAR as outlined in E-OCVM [2] and applicable to the three validation phases of Research and Development covered by SESAR (i.e. V1 to V3). Furthermore, as mentioned earlier, the SESAR HP assessment process had to ensure that HP findings from different projects can be compared, aggregated and linked back to the relevant target performance criteria.
12	12.06.09	-	Integration of CDM in the SWIM environment	The main objective of this project, named "Integration of CDM in the SWIM environment", was to specify, develop and verify an AINS prototype which is able to provide the capability to share the Airport Operations Plan (AOP) data with the Network Operations Plan (NOP) and vice versa to achieve a consistent rolling airport slots schedule and flight plans information, in order to enhance performance both at the Airport and across the Network.
13	783287	Engage	Knowledge Transfer Network proposed in response to the SESAR-ER3-01-2016 Call	[See commentary in Section 2.4 under 'gap analysis']

14	09.10	-	Approach with Vertical Guidance	The main achievements of the project P09.10 are the followings:
				• On the "standard LPV" capability:
				  ○ The functional analysis, the description of the possible aircraft architectures, and the follow-up of the standardization and regulation activities and documents for "standard LPV"
				• On the "advanced LPV" concept:
				  ○ The analysis of different innovative concepts (based on a "standard LPV" final segment) and the definition of the "advanced LPV" concept, in coordination with P05.06.03.
				  ○ The functional analysis of this "advanced LPV" concept.
				  ○ The description of the aircraft architectures that enable to perform such "advanced LPV" procedures.
				These achievements answered the following R&D questions:
				- Are these "advanced LPV" procedures feasible from the airborne side?
				- What are the airborne requirements to fly such "advanced LPV" procedures?

Project / rank	WBS	Acronym	Title	Text samples
				- Are there constraints from the airborne side on the design of these procedures? - Are there any operational requirements for flight crew to fly these procedures?
15	12.03.04	-	Enhanced Surface Guidance	The project has defined and developed a Surface Guidance Server that allows managing the complete Guidance Function, composed by D-TAXI (ground clearances and information to pilot through data link), data link for vehicle, automatic Airfield Ground and Virtual Stop Bar (VSB) for dynamic Low Visibility Operations (LVO). The project has been organised in three iterative phases. Each of them used operational inputs to derive technical specifications and one or more software prototypes. The output of each phase has been used as input for the following in order to gradually improve the quality of work and the maturity of the concept. The project used and contributed to evolve the concepts coming from projects previous to SESAR (like EMMA2 - European Airport Movement Management by A-SMGCS [4]) about Surface Guidance. The evolution has been realised thanks to the definition of more mature or new operational concepts by the project 06.07.03 ("A-SMGCS Guidance Function") and to technical improvements realised in this project.
16	LSD.02.08	RISE	RNP Implementation Synchronised in Europe	The project's objective was to demonstrate the benefits of SESAR solutions (solution #62 "Enhanced Terminal Airspace for RNP-based Operations", and solution #9 "Enhanced terminal operations with automatic RNP transition to ILS/GLS") in real life environment, focusing on lot 2 (Solutions targeting improvements in particular, but not necessarily limited to, a small/medium size airport) and specifically addressing Precision Arrival and Departure Procedures focus area. The project's objectives per airport were numerous and adapted to each airport: improve access to airport (for example by lowering the decision height), enhance safety by replacing existing circle to land procedures and defining fully managed procedures, define fully repeatable procedures avoiding non-authorized penetration of airspace, reduce track miles and fuel consumption.
17	10.08.01	-	Complexity Assessment and Resolution	The main objective of the primary project 10.08.01 "Complexity Assessment and Resolution" was to achieve a set of requirements and to develop a Local Traffic Manager (LTM) support tool to be used in several validation activities. This tool is able to assess the traffic complexity in an ATC Centre, allowing monitoring and management of the ATC Centre complexity by providing mechanisms to the LTM manager to resolve any unexpected increase of the ATCOs workload in the next few hours (30min. to 180min.).
18	12.06.08	-	Introduction of the UDPP and collaborative departure sequence	The main objective of the Primary Project P12.06.08 "Introduction of the UDPP and collaborative departure sequence" was to define the technical specifications needed for the development and verification of a prototype enabling Airspace Users (AUs) to communicate their flight priorities to the integrated Airport Runway Demand and Capacity Balancing process developed in the Operational Focus Area OFA05.01.01 (Airport Operations Management), while adhering to the requirements defined in the User Driven Prioritization Process (UDPP) concept developed separately in OFA05.03.06 (as detailed in the UDPP OSED Interim Step 1 V3 document [9]). Project 12.06.08 has been focused on the definition of technical requirements for the development of Demand

Project / rank	WBS	Acronym	Title	Text samples
				and Capacity Balancing (DCB) Monitoring Tools used in the Airport Operations Centre (APOC), which combine capacity constraints detected at the airport with the principles and rules defined in the User Driven Prioritization Process (UDPP) concept for flight prioritization. The lifecycle of the project has been based in a typical Top-Down V-model in one phase, starting with the definition of the technical specifications according to the related operational requirements and following with the prototype development and verification before the validation.
19	09.31	-	Aeronautical databases	The 09.31 project deals with Aeronautical Databases. It promotes open format DB that can be used by Avionics Systems. It deals with the following areas: • Aeronautical Data Bases data chain (applicable to all domains) • Navigation Data Bases • Airport Mapping Data Bases • Terrain Data Bases • Obstacle Data Bases The project addressed several subjects: - Aeronautical databases data Chain - Navigation databases - Airport Mapping databases - Terrain and Obstacle databases. The project was divided into 4 parts associated to each subject. For each subject standardisation, definition, prototype development and integration of database with application was performed as needed.
20	12.03.01	-	Improved Surveillance for surface management	The 12.03.01 project aimed at improving of the A-SMGCS Surveillance core function including Mono/Multi Sensors tracking, data fusion and classification/identification functionalities, and so providing the necessary surveillance information to the other airport ATC functional blocks defined in SESAR. The scope of the project 12.03.01 is the improvement of the surveillance core function for surface management. The project aimed to the development of the software prototypes validated through the validation exercises within the scope of Operational Focus Areas OFA01.02.01 “Airport Safety Nets” and OFA04.02.01 “Integrated Surface Management”

-END OF DOCUMENT-

EUROPEAN PARTNERSHIP

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