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Authoring & Approval

Authors of the document

Name/Beneficiary	Position/Title	Date
Andrew Cook / University of Westminster	Project coordinator	01 August 2022
Dirk Schaefer / EUROCONTROL	Consortium member	01 August 2022
Marc Bourgois / EUROCONTROL	Consortium member	01 August 2022
Pablo Hernandez / Innaxis	Consortium member	01 August 2022
Graham Tanner / University of Westminster	Consortium member	01 August 2022
Tatjana Bolić / University of Westminster	Consortium member	01 August 2022

Reviewers internal to the project

Name/Beneficiary	Position/Title	Date
Graham Tanner / University of Westminster	Consortium member	17 August 2022
Andrew Cook / University of Westminster	Project coordinator	17 August 2022

Approved for submission to the SJU By - Representatives of beneficiaries involved in the project

Name/Beneficiary	Position/Title	Date
Andrew Cook / University of Westminster	Project coordinator	17 August 2022

Rejected By - Representatives of beneficiaries involved in the project

Name/Beneficiary	Position/Title	Date
N/A		

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Engage

THE SESAR KNOWLEDGE TRANSFER NETWORK

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Abstract

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.

Acknowledgement

This deliverable variously draws on selected extracts and materials from other Engage deliverables and some external sources. These are appropriately referenced and credited in the text, whereas such references are not used to populate the authorship of this deliverable, which is reserved for the multiple original contributions thereto.

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1 Introduction

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

This report highlights future research opportunities for ATM. The basic framework of this work is structured around three **research pillars**, as summarised in Table 1-1. The pillars are formulated relative to SESAR's Strategic Research and Innovation Agenda, Digital European Sky [6] (SRIA), which describes the research agenda for the SESAR 3 JU. The key objective of this deliverable is complementing this Agenda with *additional* research opportunities, notwithstanding the fact that the SRIA was published some way through the lifecycle of the KTN.

Much of the work herein 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 (as described in Section 2). Each research pillar also has a dedicated section in this report.

Table 1-1. **Three research pillars**

Research pillar	Summary of pillar	Section of report
Gap analysis	A two-phase approach, firstly using a data-driven analysis of SESAR projects in the repository of the Engage wiki, using machine learning and multi-dimensional vectors to identify gaps in the existing research corpus, relative to the SRIA. The second phase deploys expert judgement to interpret and comment on the data-driven phase, to filter and focus on key findings.	Section 2.3
Thematic challenges	The goal of Engage thematic challenges was to address research topics not currently (sufficiently) addressed by the SESAR research programme. The Call for thematic challenges was open to the research community on the Engage website from January 2018. This predated the SRIA. Four challenges were devised and matured during the lifetime of the KTN using a series of dedicated workshops and catalyst fund projects.	Section 2.4
Horizon flagships	These set out to advance the definition of future research concepts beyond what is published in the SRIA. 'Horizon' reflects the familiar concept of horizon scanning in research, identifying future concepts. 'Flagship' is used as a complementary term to the SRIA 'flagship activities'. These ideas were conceived and developed by the consortium experts. The concepts are futuristic in the sense that they have not already been (fully) researched in the ATM domain, either through omission and/or because the underpinning principles are still at a very low TRL.	Section 2.5

These activities were carried out at different times during the work of the Engage 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. Since these substantial work efforts were implemented largely independently and asynchronously, it is not surprising that some overlaps between the outputs should arise. Indeed, it would be surprising had they not. This complementarity and the next stages of taking these pillars forward, is discussed in Section 4.1.

In the wider context, this report variously draws on, and relates to, other key Engage deliverables, in particular:

- D3.9: The Engage wiki – an update on the KTN's knowledge hub functionality, research maps and repository [1];
- D2.7: Annual combined thematic workshops progress report (series 3)) [2];

Notwithstanding drawing across several foundation works, this report generates a large volume of fully new material, which, it is hoped, will help to inspire future research in ATM. Combined with the reference document for the Engage wiki (D3.9), this deliverable comprises 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.

This report is also an update to the forerunner deliverable, D3.5 (Opportunities for innovative ATM research (interim report) [3]). Core recommendations cited in this report related to: (i) building research communities; (ii) transferring results of successful research projects; (iii) improving the availability and use of standard scenarios and datasets; and, (iv) insisting on the use of established scientific methods. Whilst this deliverable (D3.10) takes these recommendations forward, the reader is invited to consult D3.5 as a companion document. In particular, (iv) was taken forward by the SESAR Scientific Committee and used to develop official SESAR guidelines, now published in the STELLAR programme library, and reproduced here (as Appendix A) due to its relevance and for ease of reference.

Ten PhDs were funded through the Engage KTN. These projects are aligned with our goal of fostering the growth of a community of early-stage researchers in Europe in the air traffic management domain, as well as supporting better collaboration with industry and researchers early in the concept development stages. Through these activities, we can better facilitate the transfer to higher maturity levels through financing and access to industrial collaboration environments. Earlier reporting on the PhD programme (i.e. on the 2021 summer school [4] and the PhD consolidated progress reporting [5]) will be updated in 2022. Details of the PhDs are published on the Engage website (https://engagektn.com/phd-abstracts/).

2 Identifying and disseminating research and future opportunities

2.1 Overview of the approach

Section 2 is dedicated to detailing the methodology and results of each of the research pillar investigations, as described in the introduction, together with the full results and supporting discussions thereof. We start, however, with some insights into the broader work of the KTN, as this relates to the dissemination and accessibility of SESAR research in particular, set in the wider context. This is largely focused through the activities of the Engage wiki, which supports the work of two of the research pillars in particular, as will be explained.

2.2 Active dissemination of research – SESAR ER and beyond

2.2.1 Reprise of Engage dissemination ambitions

Much of this work stems from Task 2.2 in Engage, which is complementary to that of Task 3.4, i.e. the observatory hosting ATM research and knowledge, the Engage 'knowledge hub', which was formally launched at the SESAR Innovation Days 2020 as the 'EngageWiki'. Whilst part of these objectives were to support the dissemination of SESAR ER results and activities, Engage has gone further than this. The wiki, as described in D3.9 [1], not only provides a platform and consolidated repository with novel user functionality, but also hosts an interactive research map of ATM, which allows researchers to investigate, in various interactive modes, a full corpus of SESAR Exploratory Research *and* Industrial Research results in one place, thus delivering far more than a simple, passive dissemination platform. This thus meets the ambition of mapping ER and IR, with the planned "industrial research coordination map" included in the same tool, thus serving to "break down barriers between these research silos" (both as cited in the Engage proposal). Furthermore, as we also highlight and expand upon in the rest of this report, these efforts are brought together synergistically in the mapping and data-driven identification of future research opportunities under the corresponding research pillars, notably through the functionality of, and activities associated with, the Engage ATM concepts roadmap (another feature of the wiki). These research pillars, variously identifying research gaps and opportunities from the various perspectives of the gap analysis (examining previous research), the Engage thematic challenges (building on the workshop series) and the 'horizon' flagships (conjectures beyond 2040), are all discussed below. This synthesis of reporting, in this report, thus draws together outcomes and research mapping from the ER and IR programmes and proposes additional research elements, beyond the current level of the SRIA, for future consideration in terms of impacts on the ER programme (in particular) and on the longer-term evolution of the European ATM system.

Notwithstanding the ambition of fostering new partnerships and developing a more interconnected and collaborative ATM community, the discussion fora of the wiki (see Appendix B for links and D3.9 [1] for full details) have not gathered the hoped-for momentum at the time of producing this deliverable. It is to be hoped, that through further activities and promotion such as those elaborated in D3.9, that these fora may gather sufficient impetus to become hubs for various communications and discussions in SESAR 3.

On approval by the SJU, the two Engage 'legacy' deliverables (D3.9 and D3.10), will be e-mailed *directly* to all the Engage industry partners (who may not be party to some other lines of communication), in addition to being published on the Engage website and wiki, and direct promotion will be requested of the SJU via the SESAR *e-news*. Feedback will be invited on these reports, and such feedback will be shared with the coordinator of any new KTN launched as part of the SESAR 3 ER programme.

Full reporting communication and dissemination activities is to be found in deliverable D2.2 [16].

2.2.2 Up-to-date mapping and accessibility by the SESAR JU

The SESAR JU maintains a regularly updated mapping of the current projects, such as that shown in Figure 2-2, showing the projects by the three 'strands' ("research is categorised into three strands: exploratory research, industrial research and validation and very large-scale demonstrations. These strands have been designed as an innovation pipeline through which ideas are transformed into tangible solutions for industrialisation" [7]) and five 'key areas':

- **High-performing airport operations**, including total airport management, remote towers, runway throughput capabilities, navigation and routing tools, airport safety alerts for controller and pilots;

- **Optimised network operations**, including dynamic collaborative tools to manage ATC airspace configuration (sectors), and civil-military collaboration for greater predictability and management of operations and airspace use;

- **Advanced air traffic services**, including time-based separation and European wake vortex re-categorisation (RECAT-EU), better sequencing of traffic, automation support tools, integration of all vehicles;

- **Enabling infrastructure**, including CNS integration to facilitate economies of scale and seamless service delivery; and system-wide information management governance, architecture and technology solutions and services for information exchange;

- **U-space**, drone integration, covering technologies and service solutions to support complex drone operations with a high degree of automation in all types of airspace, including urban areas.

Dedicated pages corresponding 'projects and results' webpages offer further information under each strand, in addition to the "SESAR Innovation Pipeline", as summarised in Table 2-1. These variously contain new stories and video material. Each as a search function with filters (exemplified in Figure 2-1), generating further project links with related information, including the project's website (where applicable) affording the user up-to-date access to a full range of project deliverables.

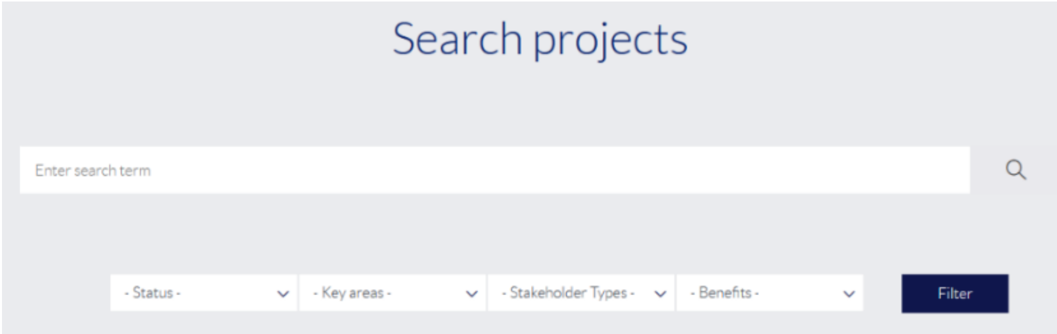

Figure 2-1. SESAR JU ‘projects and results’ webpage search functionality

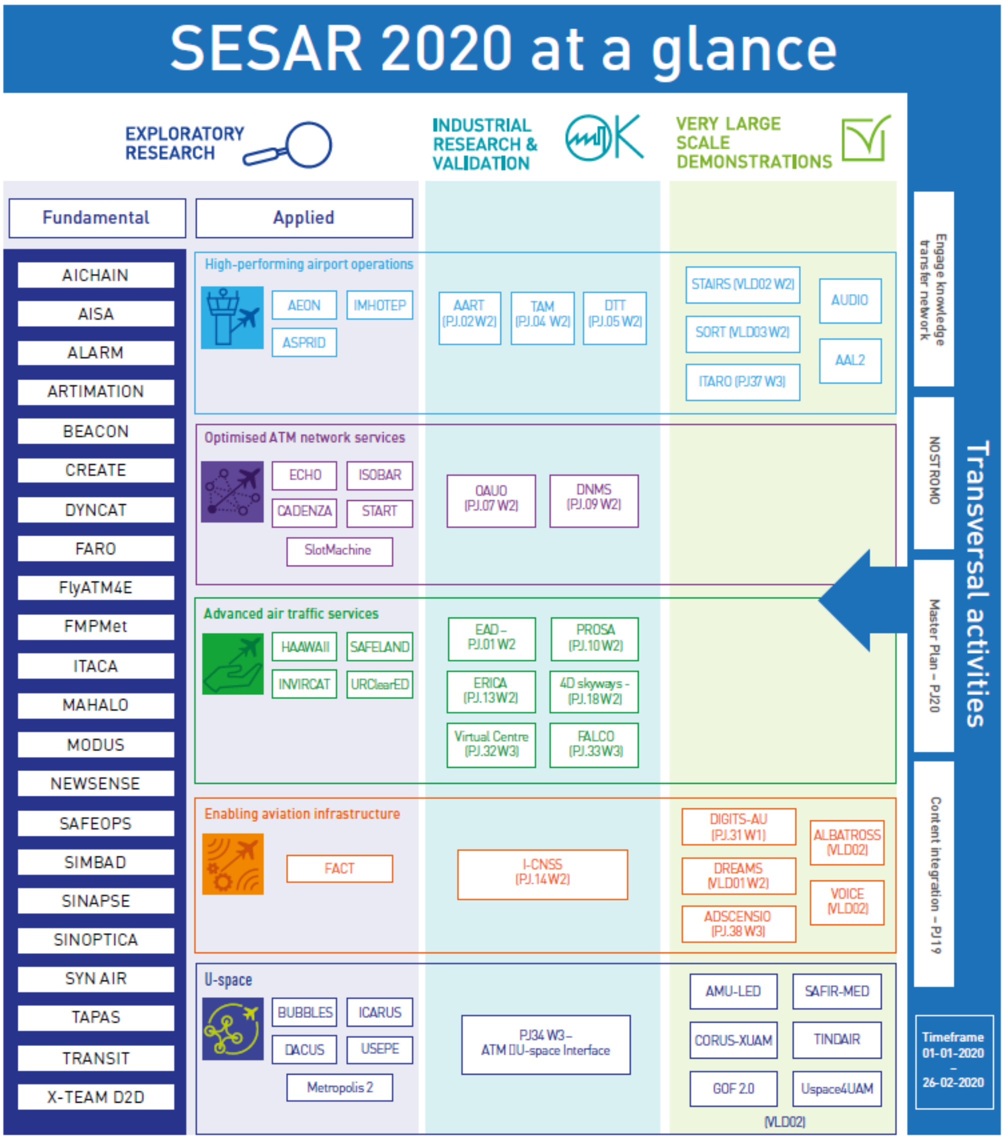

Figure 2-2. SESAR 2020 at a glance

Source: [7]

Table 2-1. **SESAR JU 'projects and results' webpages**

Text extract from webpage	Webpage research heading and link
SESAR Innovation Pipeline - SESAR projects are categorised by an innovation pipeline through which promising ideas are explored and then moved out of the 'lab' into tangible solutions for industrialisation and real operations. The pipeline consists of three distinct strands [...] Exploratory Research [...] Industrial Research [...] Very Large-scale Demonstrations	**SESAR Innovation Pipeline** https://www.sesarju.eu/innovation-pipeline
Through its Exploratory Research, the SESAR JU looks beyond the current R&D and what is already identified in the European ATM Master Plan. The aim is to investigate new ideas, concepts, and technologies, but also to challenge pre-conceived notions about air traffic management and the aviation value chain. By advancing promising research ideas and embedding them in a broader programme of work, the SESAR JU is helping to future-proof Europe's aviation industry and to maintain its global competitive edge [...]	**Exploratory Research** https://www.sesarju.eu/exploratoryresearch
Within the context of SESAR 2020, the SJU and its members have been working on two waves of industrial research projects, aiming to deliver more digital solutions to transform Europe's ATM system. In 2019, the first wave of SESAR 2020 industrial research projects came to a close, delivering a number of solutions (as part of Release 9) to the necessary level of maturity to make them available for pre-industrialisation (Technology readiness level 6 or V3). In 2020, the second wave of industrial projects were kicked off, aiming to take forward the results from the first wave and focus on solutions that can bring the most benefits in terms of environment, capacity, safety and cost efficiency [...]	**Industrial Research** https://www.sesarju.eu/node/3776
As with many things, ATM stakeholders need to try before investing in new technologies, which is why SESAR members and partners carry out flight trials and other demonstrations in real-life environments involving a wide range of operational experts, from airports, air traffic control centres, airlines, business aviation and general aviation. The fact that so many ATM actors are eager to participate is proving invaluable for accelerating the operational acceptance and the subsequent industrialisation of SESAR Solutions [...]	**Very Large Scale Demonstrations** https://www.sesarju.eu/node/3777

2.2.3 Interactive mapping and repository from the Engage KTN

Partly to support the mapping of ATM research concepts, and with a goal of building powerful interactive maps (on-line) that are easy to use and embrace both ER and IR activities, the Engage research mapping task focused on a bottom-up discovery of themes and clusters of research. Key information was extracted from previous SESAR projects, and this was used to create research themes (clusters). This contributes to the mapping of the landscape of research directions for SESAR 3. Deliverable D3.9 [1] discusses in this detail. The Engage repository and its search and filtering functionalities are also detailed. Together with CORDIS [9], and the individual SESAR project's websites, these provide a range of sources for accessing data regarding SESAR projects. In Section 4.2, below, we reflect on the different sources of project data and their recency.

2.3 Gap analysis – examining previous research

2.3.1 Methodology

The process to identify potential research gaps, identifying future research directions, deployed a phased combination of quantitative and qualitative analysis. As we detail, through an auto-encoder model (a special type of neural network) and using multi-dimensional vectors, key statistical information (e.g. keyword analysis, semantic similarity indices, outlier detection) was firstly extracted from SESAR deliverable texts in order to identify areas potentially poorly covered in the SRIA and yet with remaining potential interest to the research community. Secondly, these results were interpreted by ATM experts in the Engage consortium. The data acquisition process underpinning this is described next.

2.3.1.1 Acquiring and cleaning the source data

As described in detail in Engage D3.9 on the wiki [1], data required by the interactive research map, ATM concepts roadmap and research repository in the EngageWiki (see the live wiki at https://wikiengagektn.com/EngageWiki, and Appendix B for a summary table and specific links) consist primarily of SESAR project deliverables, Solution data packs and conference papers. The sourcing of this material started in May 2019 and continued to November 2021, feeding the updated wiki functionality. In addition to sourcing material, metadata describing each project, deliverable and conference paper were also required – this proved to be a challenging task, with a large amount of manual processing carried out for older material. Material has been acquired from the SESAR 1 and SESAR 2020 programmes:

- SESAR 1 projects and activities 2008-2016 (see Figure 2-3);
- SESAR 2020 projects and activities 2015-2024 (see Figure 2-4).

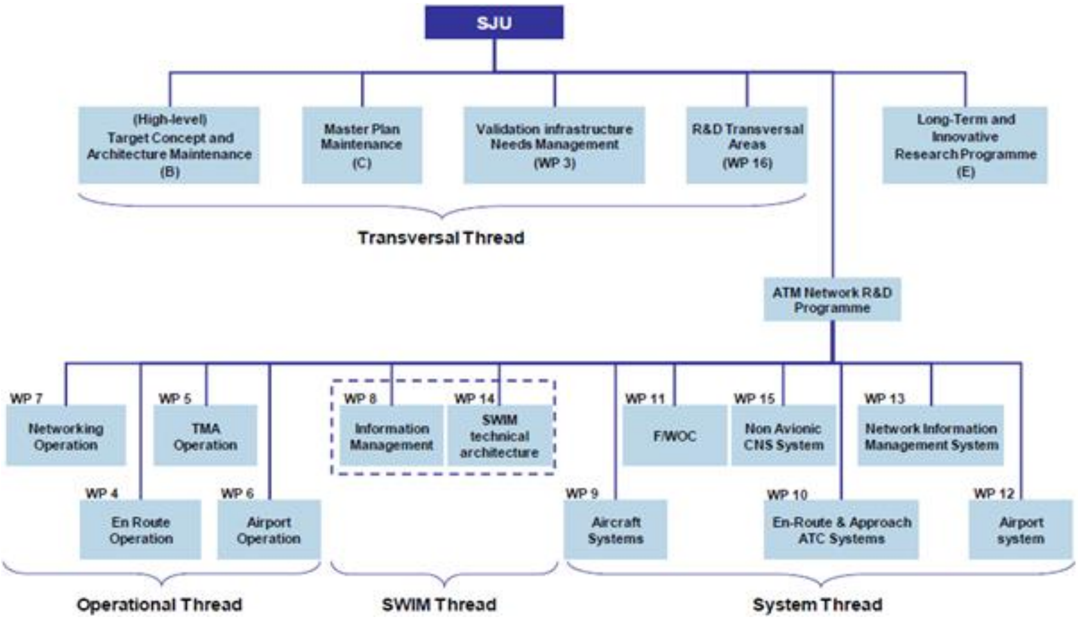

Figure 2-3. **WP activities of the SESAR 1 Programme 2008-2016**

Source: [13] (Figure 3)

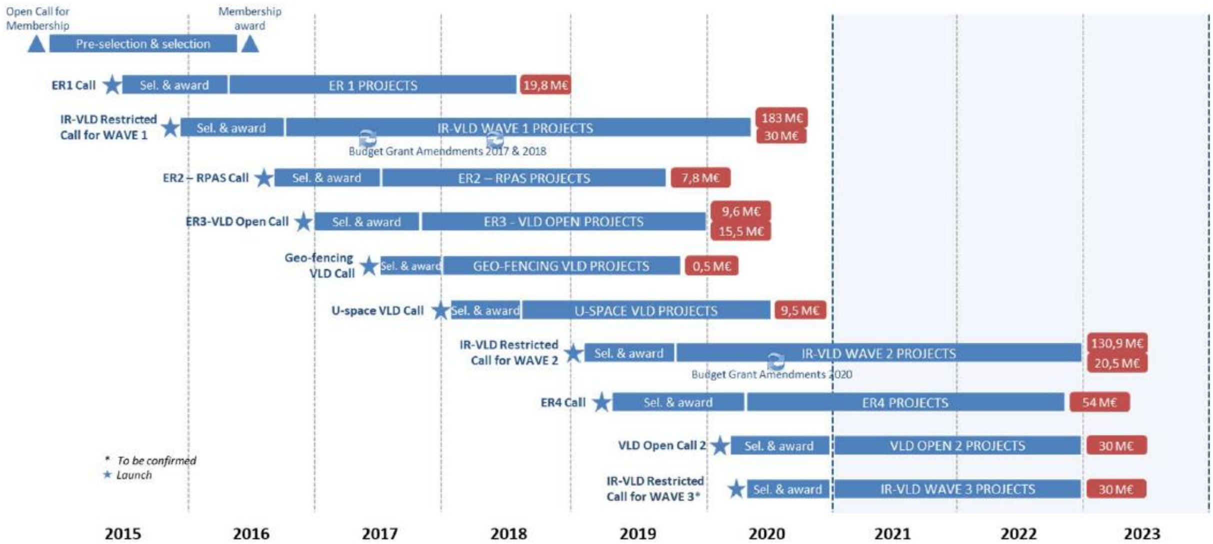

Figure 2-4. Call activities of the SESAR 2020 Programme 2015-2022, as of 2021

Source: [14] (Figure 10)

At the launch of the first public version of the wiki (December 2020), the interactive research map and ATM concepts roadmap had been developed using deliverables from 338 SESAR 1 and SESAR 2020 projects, along with papers from the annual SESAR Innovation Days conferences. However, there were gaps in the coverage of projects from SESAR 2020 Calls, missing SESAR 1 metadata and unfortunately no deliverables were GDPR-ready for publication in the repository.

Further material has since been sourced and corresponding metadata prepared by the Engage team. Of the 456 SESAR 1 and SESAR 2020 projects identified to date, material has been obtained for 426 (i.e. 88 projects added since the launch). Table 2-2 lists the SESAR Calls and projects from which material has been sourced (1873 deliverables).

Table 2-2. **SESAR material in the EngageWiki**

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	28	242
	ER3	16	172
	ER4	40	155
Total	12	426	1873

SESAR 1 deliverables were made available to Engage by the SJU from various SESAR libraries, covering industrial research Calls ('Best and Final Offer', RPAS, trials and demonstrations) and Workpackage E (Exploratory Research Calls). Whilst restricted material could be analysed for use by the interactive research map and ATM concepts roadmap, only public material could be published in the research repository after being anonymised (see Appendix B for summary descriptions of, and links to, these components of the wiki). The Engage consortium is grateful for the help given by the SJU with the task of anonymising these deliverables, to conform to GDPR requirements.

In contrast, published SESAR 2020 deliverables and Solution data packs were sourced from CORDIS [9], including industrial research waves 1 and 2, and four exploratory research Calls. Note that each Solution data pack could consist of multiple deliverables. All SESAR 2020 material could be analysed for the wiki tools, with the research repository linking back to the original material in CORDIS.

A total of 1873 deliverables have been sourced to date. Note that new material continues to be published by on-going SESAR 2020 projects.

In parallel to the sourcing of SESAR deliverables, conference papers presented at the SESAR Innovation Days (SIDs) and the USA/Europe ATM Research and Development Seminars (ATM Seminar) have been collated with the assistance of EUROCONTROL (See Table 2-3 and Table 2-4). A total of 310 SIDs papers (2011-2020) and 343 ATM Seminar papers (2011-2019) are now available in the wiki.

Known associations with SESAR projects have been 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. Note that the anonymisation of published conference papers is neither required nor desirable.

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Table 2-3 SIDs papers sourced and matched with SESAR projects for the EngageWiki

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); possible for more than one paper per project to be accepted at each SIDs.

Table 2-4 ATM Seminar papers sourced for the EngageWiki (associated projects to be determined)

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

As already summarised in Section 2.2.3, extensive initial work was undertaken to process the SESAR ER and IR textual data (deliverables) of the various projects, to be used in the following data-driven analysis.

2.3.1.2 Engage clusters and SRIA flagship activities – mapping the landscape

(a) Introducing the SRIA

Mapping the ATM research landscape is a dynamic process. During the development of the ATM concepts roadmap in Engage, the Strategic Research and Innovation Agenda, Digital European Sky [6] (henceforth simply 'the' SRIA) was published, presenting the agenda for the SESAR 3 JU. The goal of the SRIA is to support the delivery of the Digital European Sky, describing the scope of research and other actions aimed at further modernisation of Europe's ATM capabilities and U-space. Strategic research and innovation roadmaps for the years 2021 to 2027 are presented, as actions needed to deliver the implementation of the European ATM Master Plan 2020 edition. The SRIA identifies nine flagship activities/roadmaps in the 2021-2027 period, listed in Table 2-5, below. Many interdependencies can be found between the flagships, and there are three horizontal topics that should cover the entire programme. The R&I in the flagships covers the three funding instruments that will be used in the new SESAR 3 partnership – Exploratory Research, Industrial Research and Digital Sky demonstrators. The Engage consortium decided to use the SRIA as a keystone for its ATM concepts roadmap, particularly with regard to the 'forward' cluster approach of this section, and the 'reverse' cluster analysis of Section 2.5. The nine SRIA flagship activities (see Table 2-5) form a core reference point of the roadmap.

Table 2-5. The nine SRIA flagship activities (horizontal activities in bold font)

Nº	SRIA flagship activity
1	Connected and automated ATM
2	Air-ground integration and autonomy
3	Capacity-on-demand and dynamic airspace
4	U-space and urban air mobility
5	Virtualisation and cyber-secure data sharing
6	Multimodality and passenger experience
7	**Aviation Green Deal**
8	**Artificial intelligence (AI) for aviation**
9	**Civil/military interoperability and coordination**

The overall forward mapping in the roadmap is simply represented as:

projects → Engage clusters → SRIA

We next unpack this.

(b) The Engage clusters

The first steps along the pathway of mapping the research landscape was the **bottom-up building of research clusters** from the project outputs. The research clustering aimed to map the cleaned up outputs, using the plain texts extracted. Using an **unsupervised machine learning algorithm**, 14 clusters were identified, based on the similarities in project keywords (see D3.9 [1] for details, and Appendix D for a simple output list). A multi-dimensional map of these outputs was generated, and then visualised in the 'interactive research map' section of the wiki: see Appendix B for the link and [1] (Section 4.5) for details on the dynamic functionality of the map. In Section 4.2, we reflect on the different sources of project data and their recency.

(c) Mapping on to the SRIA

Next, **semantic similarity analysis** (SSA), an unsupervised NLP technique, allowed us to see how all the research previously performed (as described above) fits with the proposed nine SRIA flagship activities for 2030. It provides a single view of how it links to future research concepts, both in the SRIA, and even beyond (see Section 2.5). This identifies future research directions to be explored. In order to be able to link past and future research concepts, the objective was to find for each project in our current database, to which of the flagship activities it most related. As can be seen in Figure 2-5 (NB. 2022 clusters shown), the result of this process results in the mapping that can be seen in the left-hand half of the ATM concepts roadmap. The (initial) research clustering work has allowed us to create and visualise the temporal evolution of how the different projects from the various SESAR Calls are grouped into the 14 identified research clusters.

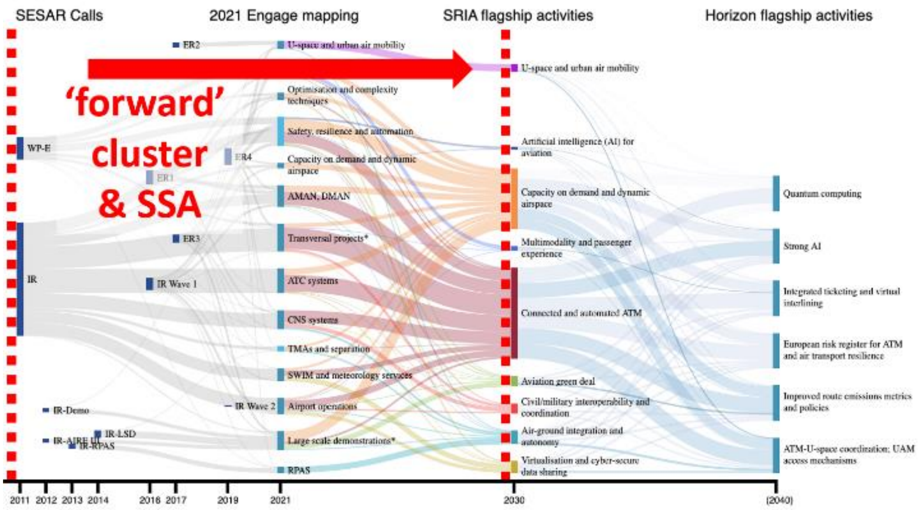

Figure 2-5. 'Forward' cluster analysis

The subsequent semantic similarity analysis scores the similarity of two texts based on how similar their words are, even if they are not exact matches. The objective of the selected algorithm was to rank the similarity of the projects with the SRIA flagship activities. To achieve this, the algorithm should be able to compare the text extracted from each of the projects with the descriptive text of the SRIA flagship activities, obtaining a measure of their similarity. The descriptive texts of the SRIA [6] flagship activities ("Problem statement"; "Description of high-level R&I needs/challenges" and "Expected high-level outcomes and performance objectives") were extracted manually and then pre-processed in a similar way to the texts extracted from the projects. A language model was constructed using **word embedding,** which allows words with similar meanings to have a similar representations in a multi-dimensional space.

This completed the 'forward' map. Again, see [1] (Section 4.5) for details on the dynamic functionality of the map.

2.3.1.3 The gap analysis method – 'within' and 'between' approaches

Having mapped the landscape, we come to the mechanics of the gap analyses. For completeness of reporting, two general types of experiment were carried out:

1. finding the 'most unique' outliers amongst the SESAR projects (a 'within' analysis);
2. finding the projects least connected with the SRIA (a 'between' analysis).

We describe and report on both methods and their results, whilst the planned focus of attention for follow-up expert analysis was (2), since this was considered the most useful for identifying future research opportunities. (Those familiar with techniques such as analysis of variance, may find the 'within' and 'between' analogies of use.)

(a) Within: finding the 'most unique' outliers

The first problem statement was thus to find the 'most unique' outliers in the corpus of SESAR deliverables (on a per-project basis). After cleaning the texts, using a similar approach to that used for the clustering[1] (as described above), the textual transformations were as exemplified in Table 2-7.

Table 2-6. Example textual transformation applied to deliverables prior to gap analysis

Before final processing	After final processing
"project overview the purpose of wp b.04.05 was to develop and validate a foundation method to identify opportunities for the provision of common air navigation services or their related functions in the context of sesar, and subsequently to examine the strategies for delivery, high level business and technical architecture options for deployment"	*"project foundation method identify opportunities provision air navigation services functions strategies delivery level business architecture options deployment"*

The texts were next **vectorised**. This converts a text into numerical features that can be seeded into any machine learning algorithm. There are many vector space models for text analysis, such as 'Tf-Idf', 'CBOW', 'Word2Vec' or 'Doc2Vec'. The one finally used was 'Doc2Vec'. Paragraph vector Doc2Vec is an extension of the Word2Vec embedding. Word2Vec tries to learn to project *words* into a latent d-dimensional space. Doc2Vec aims to learn how to project a *document* into a latent d-dimensional space. Doc2Vec randomly samples words from texts and trains one neural network model internally, which gives a numerical vector representation of the text. Using the clean text and the trained Doc2Vec model, we generated a **100-dimensional vector** for each of the projects.

An **auto-encoder model** was then used to try to identify outliers within these projects. An auto-encoder is a special type of **neural network: an unsupervised learning** algorithm that applies back-propagation, setting the target values to be equal to the input. Basically, the model tries to copy input data to output data. This process is known as 'reconstruction'. 'Hidden layers' of the network carry out the feature extraction and decoding work. At the end of all the processes, some loss is generated and the data point that is dissimilar from others incurs more loss. We used a five-layer deep auto-encoder neural network to train the model with the following layer structure: 100 → 200 → 50 → 200 → 100.

[1] This included the removal of tags (such as "<html>" and "<p>"), punctation, numeric and stop words. Stop words included common stop words (such as "like", "at", "to", "the", "and" etc.), project acronyms and project partners, words of one or two characters, and part of speech tagging (retaining only nouns and verbs), plus the ten most common and least common words. The least common words were mostly specific names or misspellings. Some of the most common *remaining* words need further investigation in fine-tuning of future analysis, but their retention was thought to have had little impact on the overall outcomes.

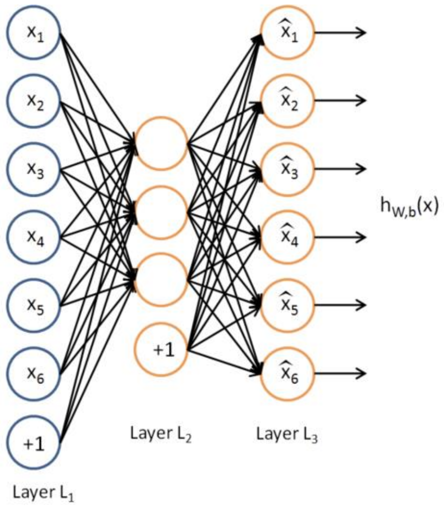

Figure 2-6. Neural network auto-encoder training

Once the output vectors were generated in order to try to identify the outlier projects, a similarity index was produced between the output vectors and the original vectors. The idea behind these is that those cases where the similarity is worse will be because the model has had problems to reconstruct it correctly and this will be due to the fact that they are projects that are further away from the others. As similarity index, the **'cosine similarity'** metric was used (Figure 2-7 illustrates). It measures the cosine of the angle between two vectors projected in a multi-dimensional space. The cosine similarity is useful as it is **not dependent on the size of the texts**. The smaller the angle between the two vectors, the higher the cosine similarity. The outlier projects are those that have a lower cosine similarity value. The results in Appendix C show the 20 'most unique' projects that obtained a lower cosine similarity value after the auto-encoder reconstruction.

(b) Between: finding the projects least connected with the SRIA

The second problem statement, our greater focus, was to find the projects with the weakest connection to the SRIA flagship activities. The initial processing and cleaning steps were analogous to those explained above in (a). This analysis builds in particular on the use of semantic similarity analysis, as used in the development of the ATM concepts roadmap, described above. The problem encountered here with word-embedding models, however, is that they fail to correctly model the technical language of aeronautics and ATM (e.g. the term 'ATM' is mainly related to money in these generic models). It was therefore decided to create a specific word-embedding model using the text of the projects, that of the SRIA flagship activities, and other extracted transport projects (in total more than 1 million sentences). The word-embedding model used was again Word2Vec. Using this proprietary model, it was possible to create a similarity matrix between pairs of words and subsequently transform the projects and SRIA texts using this similarity matrix into vector representations. In this case, the metric used was the soft cosine similarity, which is a useful implementation of the cosine similarity metric, as it also takes into account word similarity (Figure 2-7 further illustrates). The type of results produced are exemplified for three projects, in Table 2-7.

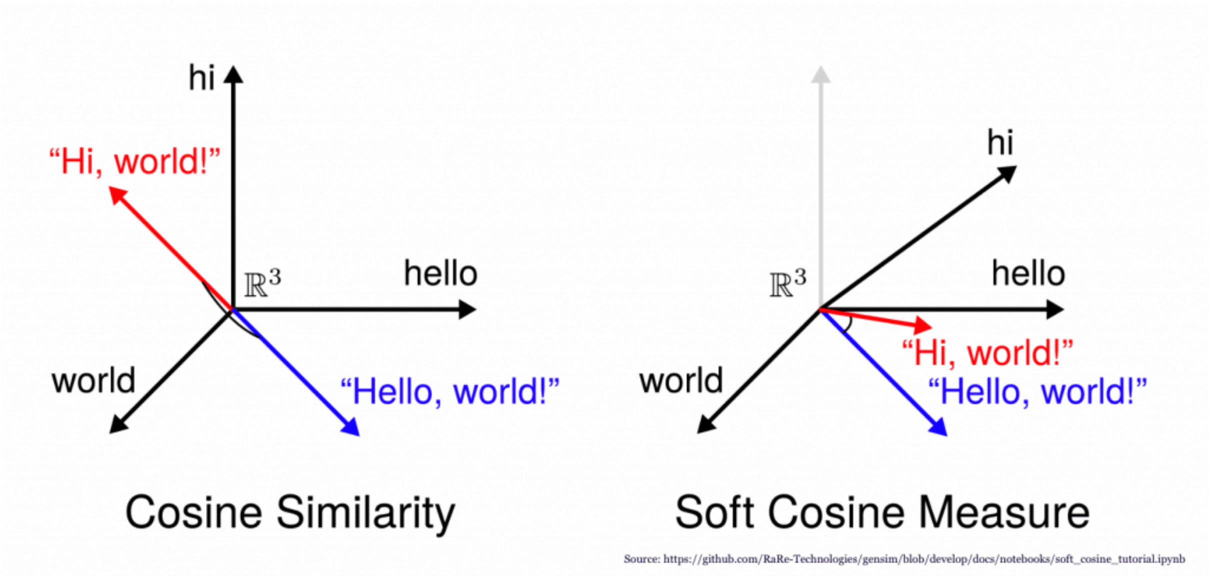

Figure 2-7. Cosine similarity and soft cosine measure

Table 2-7. Example results of the semantic similarity analysis of projects re. SRIA flagship activities

WBS	Project name	Virtualisation and cyber-secure data sharing	U-space and urban air mobility	Capacity-on-demand and dynamic airspace	Multimodality and passenger experience ...	Aviation green deal	Artificial Intelligence (AI) for aviation	Air-ground integration ...	Civil/military interoperability ...	Connected and automated ATM	Most similar topic
E.02.27	SecureData Cloud	**<u>0.23</u>**	0.09	0.20	0.20	0.19	0.16	0.18	0.16	0.22	Virtualisation and cyber-secure data sharing
LSD.01.03	Optimised Descent Profiles	0.07	0.03	0.17	0.08	**<u>0.17</u>**	0.06	0.11	0.09	0.12	Aviation green deal
14.02.03	SWIM technical supervision	**<u>0.22</u>**	0.05	0.10	0.06	0.06	0.08	0.14	0.14	0.18	Virtualisation and cyber-secure data sharing

2.3.2 Results

As the final result of this process, a semantic similarity index was obtained for each of the projects in our database with respect to the descriptions of the nine SRIA flagship activities, and the least overall connected to the SRIA are ranked in Table 2-8. 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 repository (see Appendix B) and/or the links in Table 2-1.

Table 2-8. 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.
6	12.06.02	-	The Airport Operations Plan (AOP), decision support tools and conflict detection tools	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

Project / rank	WBS	Acronym	Title	Text samples
			to be integrated in APOC for managing the overall performance of the Airport	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 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

Project / rank	WBS	Acronym	Title	Text samples
				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 main text, below]

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?
				- 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?

Project / rank	WBS	Acronym	Title	Text samples
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 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

Project / rank	WBS	Acronym	Title	Text samples
				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”

We next explore the results of the previous section and, specifically, the projects identified in Table 2-8. To avoid overly cumbersome referencing, and to improve readability, the projects 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.

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, 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.

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 [6]) 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 focussed 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.

This is addressed further in Section 3.3.4.

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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 2-8. A future KTN is, however, covered in some detail in the SESAR multiannual work programme [10].

Issues regarding the recency of the data analysed in this section are discussed in Section 4.2.2. 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 and these ideas are taken forward holistically in Section 4.1.

2.3.3 Concluding reflections on the gap analysis and the SRIA

By definition, the research ideas discussed in Section 2.3.2 are not strongly aligned with the SRIA. However, in Table 2-9, key component research ideas for the gap analysis pillar are summarised as various research 'threads'. In each case, a judgement is 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 2-9. Research threads for the gap analysis pillar & 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.
	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.

Thread	SRIA flagship(s)	Summary
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.
	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

Thread	SRIA flagship(s)	Summary
		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.

* See PJ19 (Content Integration), D4.0.050 (*Guidance to Apply SESAR Safety Reference Material*), e.g. at: https://docplayer.net/186856366-Guidance-to-apply-sesar-safety-reference-material.html

2.4 Engage thematic challenges – building on the catalyst fund projects

2.4.1 Methodology

The goal of the Engage thematic challenges was to address research topics not currently (sufficiently) addressed by the SESAR research programme. The Call for thematic challenges (TCs) was open on the Engage website between January and March 2018. The selection process resulted in (as described in detail in deliverable D3.4 [8]) four thematic challenges, to pursue:

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

All material from the workshops, namely presentations, descriptions of challenges and workshop conclusions, is public and published on the Engage website[2].

The latest edition of workshops focused on identifying future research directions under each thematic challenge umbrella, the findings of which are reported in detail in deliverable D2.7 [2].

A strong attribute of the Engage KTN is its focus on the selection of thematic challenges that require further research efforts, also offering paths to address them:

[2] https://engagektn.com/thematic-challenges

- Engage catalyst funding:
    - In wave 1, the Engage KTN funded ten projects, completed in 2020 (due to Covid-19-related delays, five projects obtained extensions of varying lengths).
    - In wave 2, the Engage KTN funded a further eight projects, that started over the summer of 2020. All the projects are now completed.

- Engage PhDs - the Engage KTN is funding ten PhD students.

The aim of catalyst funding was to further promote cooperation between industry and academia, between exploratory research (ER) and applied research, by funding focused projects, stimulating the transfer of ER results towards ATM application-oriented research. This funding has been 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).

As the thematic challenges are 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.

We focus herein on the results obtained from the third and fourth editions of the thematic challenge workshops held in 2021. Due to the pandemic, the third editions of the TC2 and TC3 workshops that were 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.

Table 2-10. List of thematic challenge workshops held in 2021

Thematic challenge	Edition	Date and place held
TC1 - Vulnerabilities and global security of the CNS/ATM system	3	15 September 2021, virtual event
TC2 - Data-driven trajectory prediction	3	25 January 2021, virtual event
TC2 - AI, ML and Automation	4	03 September 2021, virtual event
TC3 - Efficient provision and use of meteorological information in ATM	3	27 January 2021, virtual event
TC3 - Efficient provision and use of MET information in ATM	4	09 September 2021, virtual event
TC4 - Economic incentives for future ATM implementation	3	21 June 2021, virtual event

Regarding the fourth workshop of thematic challenge 2 (03 September 2021), this focused on a topic slightly different from the original one (data-driven trajectory prediction) - 'AI, ML and Automation', i.e. the scope was broadened beyond trajectory prediction and extended to include automation. Three previous workshops of this thematic challenge (TC2) addressed different approaches to improve trajectory prediction and management through data-driven techniques. Whilst some of these approaches involved probabilistic methods and statistical signal processing, machine learning accounted for the majority of techniques pursued in TC2. At the same time, machine learning approaches are applied in other ATM application areas so that exploiting the synergies between these different application areas seemed desirable. The objectives of this workshop were to bring together researchers from different Engage and SESAR exploratory research projects, and a selection of Engage PhDs, applying machine learning for trajectory prediction and also broader application areas, to identify best practices, similarities and synergies.

As mentioned, detailed reporting on the thematic challenges and workshops, with recommendations for further research, are reported in deliverable D2.7 [2]. We next give a flavour of some of the key findings from this pillar. Conclusions regarding research enablers from this pillar, emerging from the workshops in particular, are incorporated into the dedicated Section 3.3.

2.4.2 Results

2.4.2.1 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**. We reflect further on this in Section 3.3.3 (on wider community collaboration enablers), and also the importance of sharing experimental scenarios/use cases: the need for common data sets and synthetic data is reflected in Section 3.3.2 (on data enablers).

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, as we look towards 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.

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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 are indicated below.

- **Responsible disclosure**, in particular, and **sharing experimental scenarios**, in general, are significant challenges in this domain (*see main text, above*).
- 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 (*see main text, above*).
- 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.

2.4.2.2 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 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 (see also Section 3.3.2, on data enablers).

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.

A collaboration/exchange between Engage and the OpenSky Network on preparing scientific datasets for ATM is also discussed further in Section 3.3.2 (on data enablers).

2.4.2.3 TC3: Efficient provision and use of MET information in ATM

Again, in this series of workshops, data access and sharing was 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). This again is discussed further in Section 3.3.2 (on data enablers). 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, as indeed discussed in Section 2.5.2.5.

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 (*see main text, above*).
- 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**[3], and other environmental initiatives, require that environmental sustainability is addressed in all sectors, aviation included. Due to the nature of the problem

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

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.

2.4.2.4 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, see Appendix E), Think's white paper was distributed[4], 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.

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[4] This will be posted at: https://engagektn.com/thematic-challenges

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.

Published during the production of this deliverable, and connected to this theme, the reader may also be interested in Think Paper #14 from EUROCONTROL [11], which 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.

The reader is reminded that wider research ideas, from across Section 2.4, are taken forward together holistically in Section 4.1, across the three pillars.

2.4.3 Concluding reflections on the thematic challenges and the SRIA

By definition, the research ideas discussed in Section 2.4.2 are not strongly aligned with the SRIA. However, in Table 2-11, key component research ideas for the thematic challenges pillar are summarised as various research 'threads'. In each case, a judgement is 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 2-11. Research threads for the thematic challenges pillar & relationships with SRIA flagships

Thread (TCs in brackets)	**SRIA flagship(s)**	**Summary**
1 (1)		**Establish and develop a SESAR 3 cybersecurity community:** 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 cyber-attacks. Further investigations are necessary to mitigate these vulnerabilities, moving towards a cyber-resilient system, fully characterising ATM data, its confidentiality, integrity and availability requirements, taking into account the fact that new and old ATM systems will continue to operate concurrently for years to come. All these issues are especially challenging in a multi-stakeholder, multi-system environment such as ATM, where confidentiality and trust are key. Nevertheless, the cybersecurity awareness and security culture is still rather immature in ATM research, whilst there is much interest in addressing this topic and creating 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.
2 (1)		**Support a culture of responsible disclosure & sharing experimental scenarios*:** In order to improve the cybersecurity awareness and security culture research in particular, in ATM, there is a need for common data sets and synthetic data. Responsible disclosure mechanisms for research and, more importantly, for the ATM community, are particularly relevant. Such mechanisms tend to be highly bureaucratic and troublesome, complicated further for researchers by some tech companies making use of cease-and-desist orders. This is a very complex topic in cybersecurity – and for data privacy in general, across the flagships, impacting research output validation, for example (since projects use different input data).

Thread (TCs in brackets)	**SRIA flagship(s)**	**Summary**
	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.
3 (2)		**Explainable AI: explore trade-offs between explainability and performance:** Whilst explainable AI is now establishing itself as a discipline of artificial intelligence, some ML algorithms lend themselves more readily to explainability than others. Whilst it is easy to claim that all systems should be explainable, the practical value of the explanation for the corresponding use should be assessed, especially if there is a trade-off between explainability and performance, for example when two different ML models are compared.
	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).
4 (2)		**Artificial datasets for ML: avoiding training on already-cleaned scenarios:** Training ML systems on datasets where, for example, human conflict resolution is observed, will lead to a system that mimics human behaviour. 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. Two specific aspects of ML datasets 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 resolved and largely removed – so the very object of CD&R systems have largely been removed from the data. Secondly, in many cases, the (rare) 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.
	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.

Thread (TCs in brackets)	SRIA flagship(s)	Summary
5 (3)		**Climate impact: mitigation and metrics:** Various facets of climate, and the impact of aviation thereon, still need to be researched, requiring further multidisciplinary effort. For aviation climate impact, several sources of uncertainty also need to be addressed in order to measure this properly. Firstly, how to fully measure the impact, as so far only CO_2 proxies are being used, and all other emissions measurements are in lower maturity research stages. Secondly, it is important to have a method for representing the behaviour of the atmosphere, as linked to aviation emissions, on the timescales appropriate for their intended deployment.
	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.
6 (3)		**Further modelling of uncertainty in weather forecasts and climate impacts:** 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 Exploratory Research work.
	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.
7 (4)		**Incentivising early adopters: economic and behavioural mechanisms:** The Airspace Architecture Study [15] proposed a transition to a distributed architecture. Successful transition requires service providers to adopt new technologies, operational concepts, and business models. KTN discussions indicate that planned changes in ATM will not only be about technological innovation, but will include regulatory, organisational, and service evolution.
	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.
8 (4)		**Creating flexible services: ops data licencing, sovereignty and accessibility:** The question of the certification of data providers may well arise in the near future, and which data to certify. A main issue in this type of integration lies in the consolidation of information for the ATCO. Furthermore, regarding sovereignty, there is the question of which data need to be within a given State, and which can be shared. 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. An analysis of which data should be protected and which

Thread (TCs in brackets)	**SRIA flagship(s)**	**Summary**
		should be available, is needed, as this is one of the cornerstones of the Airspace Architecture Study [15].
	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 [15] vision, also tackling the issue of data sovereignty and cross-State sharing.
See Section 2.4.2 for details of these research threads; these are *examples only*		
* Proposed in particular w.r.t. cybersecurity but applies across many other domains. See also thread (4).		

2.5 'Horizon' flagships – 2040 and beyond

2.5.1 Methodology

Looking further ahead, Engage set out to advance the definition of future research concepts and directions beyond what is already published in the SRIA. The nomenclature 'horizon' flagship activities is used. 'Horizon' reflects the familiar concept of horizon scanning in research, identifying future concepts. 'Flagship activities' is 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) are still 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 is difficult to justify their relevance to ATM, considering the relatively broad scope and maturity of the SRIA. The timeline indicated below, "(2040)", is somewhat illustrative, in that some ideas could be partially developed at higher TRLs sooner, others later.

As with the forward cluster analysis, these are mapped onto the SRIA flagship activities to show the strength of the relationships between the two flagship activity types. The current mapping is shown in Figure 2-8 (i.e. 2022 clusters shown). Based on these texts, for each flagship activity, the reverse cluster comparative analysis illustrates the stronger and weaker links between the flagship types. This is represented in the ATM concepts roadmap by variations in the colour intensity of the link, thus providing a visualisation of the level of connection and co-coverage of the SRIA flagship activities and the future concepts identified by Engage. (The link intensities may be somewhat better visualised by hovering over the horizon flagship activity nodes, for example.) This will be taken up quantitively in the analyses of Section 2.5.3.

These activities may be updated and further populated through continued research, drawing on outputs from Engage, more widely in SESAR, and even beyond ATM, through wiki user inputs, and including interdisciplinary concepts, during SESAR 3 (see Section 4).

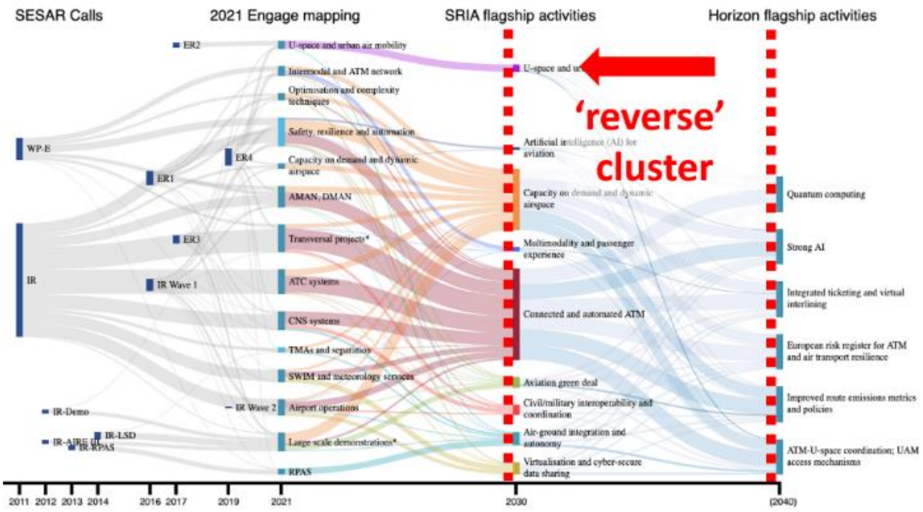

Figure 2-8. 'Reverse' cluster analysis

2.5.2 Results

The six horizon flagship activities proposed for seeding the ATM concepts roadmap are presented in the following sub-sections, in no implied order of priority. In addition to the next steps relating to the concepts roadmap, outlined above, the *broader* development of these new research directions is taken forward in Section 4.1.

2.5.2.1 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.

2.5.2.2 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 DeepMind5, 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[6] 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

[5] https://venturebeat.com/2021/06/09/deepmind-says-reinforcement-learning-is-enough-to-reach-general-ai/

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

approach could be extended more widely to larger systems, and help to build better predictive models 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.

2.5.2.3 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[7] 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.

[7] https://accesrail.com/

2.5.2.4 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 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"[8]).

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.

2.5.2.5 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[9] 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

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

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

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.

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[10], 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.

2.5.2.6 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.

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

(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 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.

2.5.3 Concluding reflections on the horizon flagships and the SRIA

By definition, the research ideas discussed in Section 2.5.2 are not strongly aligned with the SRIA. However, in Table 2-12, the top three semantic similarities are indicated, between the six horizon flagships (Engage threads) and the SRIA flagships, using the descriptive texts of Section 2.5.2 and as per the methodology of Section 2.3.1.3. (This table thus partly reflects and quantifies the links in the right-hand-side of Figure 2-8.) The blue text refers to the SRIA flagship names and numbers. The black bold captures the horizon flagship names. One of the strongest relationships in the table can thus be seen to be that between “strong AI” (Engage horizon flagship) and “Artificial intelligence (AI) for aviation” (SRIA flagship), with a similarity of 0.66. This is a logical association, adding validatory weight to the approach, as do the other relationships in the table. It is also worth noting that most (4/6) of the highest similarities are reflected through *transversal* SRIA flagships (7 and 8 – see Table 2-5).

Table 2-12. Semantic similarities between SRIA flagships and Engage horizon flagships

Thread	SRIA flagships (cosine semantic similarity)	Engage research threads and aligned SRIA flagships
1		**Quantum computing**
	8 (0.36)	Artificial intelligence (AI) for aviation
	1 (0.29)	Connected and automated ATM
	5 (0.25)	Virtualisation and cyber-secure data sharing
2		**Strong AI**
	8 (0.66)	Artificial intelligence (AI) for aviation
	1 (0.48)	Connected and automated ATM
	7 (0.39)	Aviation Green Deal
3		**Integrated ticketing and virtual interlining**
	6 (0.64)	Multimodality and passenger experience
	7 (0.37)	Aviation Green Deal
	3 (0.34)	Capacity-on-demand and dynamic airspace
4		**European risk register for ATM and air transport resilience**
	8 (0.41)	Artificial intelligence (AI) for aviation
	7 (0.39)	Aviation Green Deal
	6 (0.36)	Multimodality and passenger experience
5		**Improved route emissions metrics and policies**
	7 (0.62)	Aviation Green Deal
	6 (0.47)	Multimodality and passenger experience
	3 (0.44)	Capacity-on-demand and dynamic airspace
6		**ATM-U-space coordination; UAM access mechanisms**
	4 (0.73)	U-space and urban air mobility
	2 (0.53)	Air-ground integration and autonomy
	1 (0.49)	Connected and automated ATM

Following the same approach of Table 2-9 and Table 2-11, in Table 2-13 the horizon flagships pillars are indicated alongside the best aligned SRIA flagship activities (albeit this time drawing on the quantification of Table 2-12, flagging up to two flagships with semantic similarities > 0.40), and some commentary is presented on the key relationships between the Engage threads and the SRIA flagships. 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 2-13. Research threads for the horizon flagships pillar & relationships with SRIA flagships

Thread	SRIA flagship(s)	Summary
1		**Quantum computing:** Quantum computers use quantum physics properties to enable certain types of computations to be performed vastly quicker than classical computers. A fundamental advantage of quantum computers is the ability to consider large numbers of combinations simultaneously. 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. Quantum computing is likely to bring particular opportunities for simulation, especially when coupled with machine learning and AI.
	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).
2		**Strong AI:** this is also known as general AI or artificial general intelligence, usually referring to a form of AI whereby a computer has intelligence comparable to that of humans, with the ability to solve problems, learn, and plan future contingencies. Reinforcement learning is arguably a sufficient basis for strong AI, e.g. with the inclusion of agents that learn through interaction with the environment through operational sensors. Coupled with deep neural networks, more powerful dimension reduction and polynomial classification, such technologies could help to build better predictive models from specific aircraft and component safety profiles through to full socio-technical system models at the design stage.
	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.

Thread	SRIA flagship(s)	Summary
3		**Integrated ticketing and virtual interlining:** Europe remains largely in a fragmented modal service culture. Importantly, single ticketing and virtual interlining already exist in some formats, such as specific rail-air collaborations, and some wider schemes (e.g. through IATA). A comprehensive review of existing single-ticketing solutions and identification of the benefits, barriers and lessons learned is needed in order to build upon and extend these models in an integrated manner with ATM. 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.
	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.
4		**European risk register for ATM and air transport resilience:** a higher-level, European risk register is suggested, taking account of space 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. Learning from the past experience of the European Aviation Crisis Coordination Cell and various broader, national risk registers, could indicate which type of risks to include, how best to monitor the emerging strategic and (pre-)tactical situations, and being overall proactive in calling up crisis cells.
	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.
5		**Improved route emissions metrics and policies:** non-CO_2 emissions are responsible for roughly 75% of aviation's global net effective radiative forcing. The impact of NO_x and contrails depend on many factors, including flight level, atmospheric conditions, time of day and year, and geographic latitude, and is to date not fully understood. Contrail-optimised flight routes may increase the fuel burn and hence also CO_2 emissions, leading to the necessity to trade-off various climate impacts. Environmentally friendly (e.g. contrail- or NO_x-optimised) routes might well be longer, increase fuel burn, related costs and flight times. Since the *flown* flight plan is now the basis for route charging, this may also result in longer but overall cheaper routes resulting in higher emissions.

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Thread	SRIA flagship(s)	Summary
	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.
6		**ATM-U-space coordination; UAM access mechanisms:** U-space is a crucial building block for the deployment of unmanned aerial systems and UAM. Notwithstanding on-going implementation research, including VLDs, open questions remain regarding ATM-U-space coordination, e.g. regarding the structure of U-space airspace and segregation, and the operation of vertiports. Furthermore, different vehicles and types of operations will exist in U-Space (especially for UAM), including police/surveillance operations, delivery of (e.g.) medical supplies, and air taxi operations. Studies on societal acceptance and with ATCOs suggest different degrees of willingness to prioritise these different operations, further complicated when piloted flights are admitted to U-Space/UAM.
	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.

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3 Practicalities and enablers of supporting future research directions

3.1 Introduction – scoping the enablers

In addition to identifying new and continuing areas for research in future, as set out in Section 2, in this section the practicalities and 'enablers' of such research are discussed. Some of these enablers are distinct mechanisms (such as catalyst fund projects, community collaboration), whilst some others have a higher research content *per se*, such as the development of broader performance metrics, but were included here more as horizontal / supporting activities, which immediately relate to the wider corpus of research work discussed in Section 2. Others, such as synthesising and sharing data collaboratively, lie some in between the two. First to be considered are the lessons learned from the Engage catalyst fund projects.

3.2 Learning from the Engage catalyst fund projects

3.2.1 Background and reporting

Engage funded 18 catalyst fund (CF) projects (they are listed in Appendix E, showing their individual reporting, and recently summarised through their workshop activities in D2.7 [2]). The funding was used to support focused, 'light touch' projects. The focus was on maturing exploratory research further towards applications and operational contexts. The projects were able to address the corresponding thematic challenges. 'Open' proposals were also a way for projects to move solutions closer towards industry goals and objectives, and towards higher TRLs (one of the 18 was funded this way), whilst priority was given to those aligned with thematic challenges, as described in the two funding Calls (outlined in [2]). An Awards Board comprised Engage consortium members, the SESAR Joint Undertaking, ASDA and industry partners (without conflicting interests), and was chaired by EUROCONTROL. Engage consortium members were self-determined to be ineligible to bid for the funding, in order to distribute funding back to the research community at large.

For final reporting, each catalyst fund project prepared two reports using templates supplied by Engage: a confidential **final progress report** and a public **final technical report**. The reviewing of final reporting was carried out within the Engage consortium by the two mentors assigned to each project, plus the Engage coordinator. Approval followed any requested clarifications or amendments to the reports.

The final technical reports are published on the *Engage catalyst fund project summaries and reporting* web page[11]. Each final technical report (see Appendix E) will be republished on CORDIS on acceptance of the formal Engage deliverable by the SESAR JU. Note that original catalyst fund project authorship is retained on the cover page of each such Engage deliverable.

[11] https://engagektn.com/cf-summaries

3.2.2 Lessons learned

Each final technical report includes a dedicated section on lessons learned, which are reported separately and are of value within the specific technical context of the individual projects. Here, however, we draw together the broader feedback of value to the research community in general, and SESAR 3 in particular, for helping to shape any future, similar mechanisms. The final reports requested and offered the projects an opportunity to provide feedback on what worked well and what could be improved with the catalyst fund approach.

The catalyst funding scheme (EUR 60k maximum budget allowed through the Horizon 2020 'cascade' funding mechanism – most projects requesting close to this maximum) supported projects for an intended 12 months' duration (although several were somewhat delayed due to the Covid-19 pandemic [2]). 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 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 researchers to focus on the actual research. Furthermore, the administrative and mentoring support offered by the Engage KTN team was greatly appreciated.

Regarding barriers in the process, and points for improvement, some such were raised regarding the administration tasks. The 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. Additionally, it could be useful for new projects to be provided with a brief on the scope and responsibilities of the project mentors to better utilise their input. From the coordinator's perspective, the additional tasking of arranging contracting with each project, and the process of invoicing via the university financial control system, required significant additional effort. These factors should all be considered in any similar mechanism operated through any KTN launched under the SESAR 3 ER programme.

The proposal, and subsequent mentoring and reporting, offered quite a flexible project structure, it was reported, allowing the project team to explore a variety of ideas and determine future directions for development. The freedom to make several minor adjustments during the project was welcomed equally by projects at early stages of exploration and by those at higher (initial) TRL levels. However, the proposers should keep in mind that the flexibility should be balanced by setting achievable targets and tasks, given the size of the project.

The CF funding scheme was considered, by the Engage consortium and the project leads, to be a good instrument for a variety of TRL projects, from initial idea exploration, to focused, agile development of ATM solutions. The projects at all TRL levels highlighted the importance of early and continuous collaboration with their targeted stakeholders. Various forms of collaboration were applied by projects – from direct collaboration with the end-users (as a project partner), through individual interviews, to the extensive use of advisory and/or focus groups. This was indeed one of the evaluation criteria of the proposals. This potential barrier was thus generally perceived as being well managed.

Regarding stakeholder involvement, having an Engage KTN network of contacts in key organisations (such as EASA, EUROCONTROL, certain ANSPs, etc.) to whom to turn for specific questions, was highlighted as a positive provision, which could be enhanced further in future. The Engage KTN network of contacts (e.g. industry partners) participated directly in the CF mentoring and related tasks. However, as this was on a voluntary basis, the particular contact might not be available at the time needed and for the effort required. The overall impact of a more structured use of KTN contacts on the agility of the adopted process might be explored further in future.

Realistic estimation of effort and time on various tasks was cited as a lesson for project leads. The examples of underestimated tasks included data acquisition, cleaning and preparation, choice of validation periods (to include the specific events needed for validation), material acquisition time (e.g. unfortunately the Covid-19 situation often delayed deliveries), and the time needed for organisation of workshops intended for specific audiences (notwithstanding specific Engage support, in *addition* to the framework of dedicated, annual thematic challenge workshops (detailed in [2], which were well received by the projects and other delegates, alike).

Overall, the CF funding scheme was positively evaluated by the projects. CF recipients requested the retention of such a scheme in the SESAR 3 programme. One suggestion was to allow project durations longer than one year, to allow more time for publication and dissemination (as in many areas of ATM it is often impossible to publish a paper in less than a year). This would have to be assessed against the principle of refreshing the thematic challenges during the lifecycle of the KTN, as was part of the executed plan, although all the original challenges in wave 1 were ultimately retained in wave 2 of the funding [2]. Although slightly larger next stage funding rounds (e.g. EUR 150k), aimed at conducting small-scale validation exercises, were suggested by some projects, this is currently not permissible under EU framework rules, as mentioned above.

The consortium would like to close by remarking on how positive the experience has been working with the 18 project teams, the remarkable level of technical outputs achieved by very many of the projects with such relatively limited resources, and the degree and extent of industry collaboration, as evidenced through their contributions at the TC workshops (often alongside larger projects), and indeed through their formal reporting.

3.3 Research enablers

3.3.1 Open access to scientific publications and research data

Research results obtained in the SESAR programme are of broad interest and based on public funding; they should hence be made freely available to the research community as well as industrial or institutional stakeholders. We strongly believe in and subscribe to, open publication principles. The principles of open access to publications and data are laid out by the European Commission in the H2020 open access and data management policy[12].

In contrast to open publication standards, many journals and conferences are commercially oriented, selling access to research publications such as conference papers and journal articles. This leads to the somewhat ironic situation that authors have to acquire the ‘privilege’ to distribute articles they have written and submitted to a journal, often paying four-digit amounts per article. This clearly is an

[12] https://ec.europa.eu/research/participants/docs/h2020-funding-guide/cross-cutting-issues/open-access-dissemination_en.htm

impediment to open access to research results and should be (largely) discouraged. A number of vehicles for open access publication are available. We suggest that the following recommendations are made to research projects involving public funding, including SESAR 3.

(a) Open access to publications

Each beneficiary ensures open access to all peer-reviewed scientific publications relating to the results of the research project. The main mechanism for this will be 'green' open access (self-archiving), where the beneficiaries deposit an electronic copy of the peer-reviewed and accepted manuscript in an online repository, typically no later than one month after its publication. To this end:

- all scientific publications should be freely and publicly available for download from the project website;
- the project should publish results in scientific conferences with an established policy of making all articles freely available for download on the conference website (e.g. SESAR Innovation Days, US-Europe ATM R&D Seminar, International Conference for Research in ATM – ICRAT);
- project members are encouraged to publish articles they have authored or co-authored on appropriate archiving platforms, such as ResearchGate (https://www.researchgate.net/) and ZENODO (www.zenodo.org);
- publications being hosted by a KTN repository are also encouraged (see Section 4.2.2 regarding future suggestions).

In other cases, the project may budget for 'gold' open access publications and project results may be submitted to scientific journals that (otherwise) charge the research community for these articles either on a per-access basis (or by selling gold open access). This includes regular journal submissions as well as articles in special issues. In this case, the project should acquire gold open access for the articles it produces, but this option should be reserved for particular cases, with clearly allocated budgets at the proposal stage, rather than being the norm. It is noted that academic institutions may have special relationships with publishers and specific journals, and/or national requirements for research publication may drive more material through one pathway (such as gold open access) than another. Gold open access may sometimes be complicated by cost ineligibility after project closure, since publication processes can be protracted.

(b) Open access to research data

Research data is information (particularly facts or numbers) collected to be examined and considered, and to serve as a basis for reasoning, discussion or calculation, especially with a view to reproducing the results and conclusions in peer-reviewed scientific publications. Upon publication of a peer-reviewed scientific article the underlying datasets should be examined with a view to the possibility of making them available to the research community, either through the project website or using appropriate vehicles such as OpenAIRE (https://www.openaire.eu/), or the publishing journal itself. Mindful of the need to avoid resource duplication, vehicles such as the Engage repository may also be valuable for deposits of data and/or code. This is pursued in the next section.

3.3.2 Data and code issues

Further to the preceding discussion, 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 approximately 6-12 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[13], launched at the 2020 Engage summer school; ADS-B data from the OpenSky Network[14]), 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 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.

Specific issues flagged in the particular thematic challenge workshops (as detailed in D2.7[2]), may be summarised as:

- TC1: data access and (scenario) sharing is especially limited in the cybersecurity context, placing a particular potential emphasis on the use of *synthetic* datasets (see also the machine learning context, below); this would also be useful for meta-analyses from different simulations and sharing with other projects / application contexts;
- TC2: a collaboration/exchange between Engage and the OpenSky Network on preparing scientific datasets for ATM is to be driven by the (Engage) KTN and the PhDs' and researchers' needs were correspondingly discussed (*follow-up is pending*);
- TC3: a specific challenge in the MET context is acquiring homogenised data for the entire European airspace (e.g., MET data, GNSS, lightning);
- TC4: as flagged in Section 2.4.2.4; it seems, currently, that the fear of misuse and similar issues is much higher than the use actually requires; data availability and proprietary licensing could be significant barriers to the creation of flexible services – i.e. whereby access to data is limited behind cost and disclosure walls.

[13] https://www.eurocontrol.int/dashboard/rnd-data-archive

[14] https://opensky-network.org/

(a) Synthetic training data for ML models

Synthetic data is a particular issue for ML models. These require large data sets 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. (The reader is also referred to the discussion in Section 2.4.2.2.)

(b) 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" [12]. The first Call was launched on 17 November 2021, and it foresees to fund preparatory action for the common European mobility data space (through a Coordinated and Support Action (CSA)). The CSA should also identify current mobility data sharing initiatives, gaps, overlaps and potential common building blocks. The common building blocks and governance framework 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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The above issues relating to data sharing and availability, apply in large part to the sharing of code, in terms of efficient use of researcher effort (not having to have multiple inventions of the same code to solve one problem), accessibility and availability. Again mindful of the need to avoid resource duplication (e.g. cf. GitHub[15]), vehicles such as the Engage repository may also be valuable for deposits of code (with some such having already been made).

[15] https://github.com/

3.3.3 Community collaboration

Throughout all the workshops, the need for, and benefits of collaborations (on different topics) continue to appear. Here we mention the topics of collaboration identified in various TCs:

- 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. (See also Section 3.3.4.)

- 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. (See also Section 2.4.2.3.)

3.3.4 Extending the SESAR KPI state of the art (e.g. on fairness and equity)

A core horizontal task across the ER and IR programmes is the continued development of appropriate KPIs. Flagged in the previous section was the possibility of establishing a dedicated and integrated community to this effect. The specific domains of trajectory prediction (efficiency) and environmental (climate) impacts were cited.

There is a growing need to extend such considerations to the multimodal context, with on-going work in ER4 addressing such issues, and reporting on the (H2020) CAMERA CSA[16] also making extensive and useful recommendations in this domain (through its *Mobility Report 4*).

Whilst there is a widespread consensus that the air transport industry must be integrated and sustainable from both an economic and environmental point of view, relatively little attention is devoted to equity or fairness. These concepts are difficult to define (i.e. the same definition for all stakeholders, and across solutions) but are very important for acceptance of new solutions. There are as many notions of fairness and equity as there are problems. Moreover, often the terms ‘fairness’ and

[16] https://h2020camera.eu/the-project/

'equity' are used interchangeably. The first step would be to define the difference between the two. The first-come first-served (FCFS) flow management strategy is historically considered fair in the ATM context. However, the consequences of a particular solution, even in the FCFS strategy can be considered unfair. For example, the distribution of assigned delay can penalise some airlines more than others.

However, the introduction of fairness comes at a cost. This can be seen on at least two levels. At a more operational level, it is not difficult to show examples in which a 'fair' solution for airspace users (for example for the allocation of slots) can be more expensive for the system (the network) than an 'unfair' one, i.e., less economically sustainable leading to worse KPIs.

At a more macro-economic level, not all actors in the air transport system enjoy the same protections in cases of adversity: airlines fail, ANSPs and airports do not. Understanding and quantifying the trade-offs between the level of economic and environmental sustainability, and the level of equity or fairness is by no means trivial.

Different notions of fairness can be considered, such as egalitarian social welfare (expressed as the minimum utility of any agent), proportional fairness (an allocation for which the sum of each agent's difference in utility is positive does not exist), or envy-freeness (where no agent prefers another agent's outcome).

As discussed in 2.5.2.6, fairness could constitute a potential indicator in the future U-space performance framework and research could explore the need for 'fairness' services in U-space, e.g. fairness monitoring, or the need to incorporate fairness considerations in some U-space services, e.g. fairness in authorisation/strategic de-confliction, fairness in demand and capacity balancing.

3.3.5 Distributed and remote simulations

A variety of simulators exist in air traffic management research, ranging from low-fidelity environments for early concept development to large-scale, high-fidelity control-room simulators. The choice of the 'right' simulator is a trade-off between experimental control and realism, as well as the maturity of the concept and system under development.

Technological advances, as well the Covid-19 pandemic, have made distributed simulations possible and desirable. Large-scale, high-fidelity control-room simulators will continue to be required; yet, costs savings as well as the possibility to attract a larger number of participants, make distributed simulations particularly suitable for small-scale and low-fidelity simulators.

Simulator interoperability has been studied over the past few years, e.g. in EUROCAE's Working Group 84, with a view to connecting different simulators, typically of higher realism. Yet, further 'virtualisation' seems possible and desirable. For example EUROCONTROL has recently added functionality to its ESCAPE simulator that allows pseudo-pilots to control simulated aircraft from any location (including home), rather than from the control room in Brétigny.

Going even further, remote simulations may be imagined based on simulation suites, which participants can install on their computer, or access via the internet. This might allow the boosting of participant numbers by being location and time-zone independent, and allowing for a more flexible and iterative design process, especially in design evaluation in the lower maturity phases. Admittedly, some downsides must be considered, for example reduced experimental control.

4 Building further in SESAR 3: conclusions

This section summarises key handover material for SESAR 3: focusing firstly on the research directions proposed, and then on the corresponding platforms.

As flagged earlier, on approval by the SJU, the two Engage 'legacy' deliverables:

- D3.9: The Engage wiki – an update on the KTN's knowledge hub functionality, research maps and repository);
- D3.10: Research and innovation insights;

will be e-mailed *directly* to all the Engage industry partners (who may not be party to some other lines of communication), in addition to being published on the Engage website and wiki, and direct promotion will be requested of the SJU via the SESAR *e-news*. Feedback will be invited on these reports, and such feedback will be shared with the coordinator of any new KTN launched as part of the SESAR 3 ER programme.

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4.1 Research directions

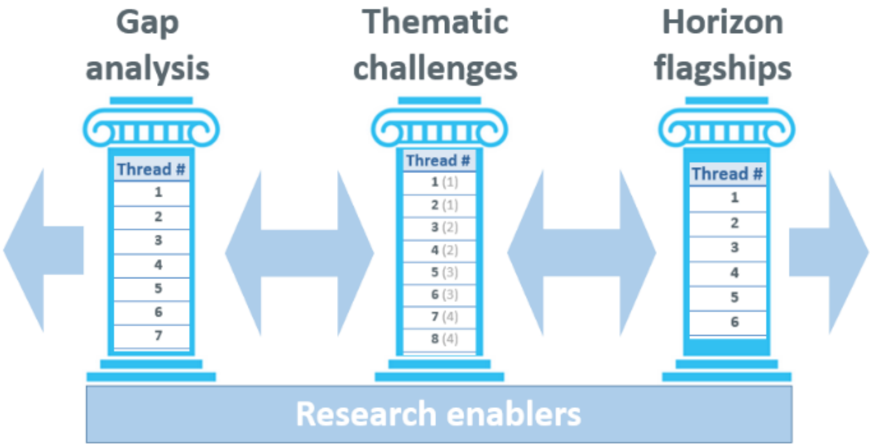

Figure 4-1. Research pillars, threads and enablers

Figure 4-1 shows the three research pillars introduced in Section 1. Their corresponding results were presented in Section 2.3, Section 2.4 and Section 2.5. Each pillar may be conceived of as comprising various 'threads', i.e. their key component research ideas. These threads are summarised in the tables below (which simplify those in sections 2.3.3, 2.4.3 and 2.5.3).

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 R&I.

Table 4-1. **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.

Thread	SRIA flagship(s)	Summary
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.
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.

* See PJ19 (Content Integration), D4.0.050 (*Guidance to Apply SESAR Safety Reference Material*), e.g. at: https://docplayer.net/186856366-Guidance-to-apply-sesar-safety-reference-material.html

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 described in Section 2.3.1.3 for the gap analysis, using an auto-encoder (unsupervised ML) model. This environment and such activities may be supported by the research enablers described in Section 3.3 (several of which themselves require further research activity and development), and of course by other enablers.

Table 4-2. **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).
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.

Thread	SRIA flagship(s)	Summary
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 [15] 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 SESAR 3 JU consider this appropriate.

Through the Engage wiki, 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 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, Section 4.2.

Table 4-3. **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.
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.

Thread	SRIA flagship(s)	Summary
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 Research platforms

4.2.1 Bridging the wiki gap to SESAR 3

In addition to the already guaranteed support to keep the wiki passively in operation well into SESAR 3, D3.9 [1] sets out additional support, which could be provided by some members of the current consortium, subject to a new contract (irrespective of the funder), for example designed for the period before any KTN is launched within SESAR 3, to maintain the wiki in a more active mode. This includes:

- adding one batch of new, pre-anonymised (by the providing party; supplied with appropriate input metadata) materials to the EngageWiki repository, as one action (i.e. not dispersed over several months);
- carrying out one new research clustering and update of the interactive research map;
- carrying out one new forward cluster, or gap analysis, providing (uninterpreted) raw output for further research purposes by interested parties;
- adding new horizon flagships to the ATM concepts roadmap and mapping them to the SRIA;
- supplying and executing (as appropriate) communications on the above tasks in a manner preferred by the SESAR 3 JU communications team.

4.2.2 Sources of project data – consolidation and recency

In Sections 2.2.2 and 2.2.3, the different approaches of the top-down SESAR mapping, and the data-driven, bottom-up clustering undertaken in Engage, were presented. The Engage repository and its search and filtering functionalities were also summarised. Together with CORDIS [9], and the individual SESAR project's websites, these provide a range of sources for accessing data regarding SESAR projects.

The extent to which it is desired to consolidate these processes and focus on one single source, is a question for the SESAR 3 JU 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.

Underpinning this, 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 (see D3.9 [1] Sections 2-4); 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 SJU colleagues in support.

In D3.9 [1] Section 3, we also discussed 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 presented herein.

Further challenges to be overcome include obtaining such 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). This means that there were currently some inevitable gaps in the analysis of Section 2.3, for example, due to the incomplete set of data directly available as inputs into the process. 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.

4.2.3 Wiki registration and security

Deliverable D3.9 [1] presented lessons learned relating to wiki user registration and participation, plus protection from external (bot) attack and the secure, remote storage of files on Amazon Web Services. A full review of these lessons learned is recommended to be carried out by any KTN launched within SESAR 3, in consultation with the SESAR 3 JU. The current KTN coordinator would put itself at the disposal, *gratis*, of parties engaged in such a review, for corresponding matters of clarification.

Complementarily to this, the EngageWiki hosting and domain are both secured with sufficient longevity to hand over all licensing and access control to any future KTN in SESAR 3, should this be required. Full and sufficient details would be disclosed to the SESAR 3 JU, by the current KTN coordinator, on request and without delay, to effect a smooth transition to any such successor KTN.

4.2.4 Wiki discussion fora

Through several activities described in D3.9 [1], 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. *Examples* mentioned are hosting discussions around specific technical sessions of the SESAR Innovation Days or to encourage inter-project researcher collaboration across a SESAR 3 research topic (e.g. multimodality), even integrating across ER-IR on specific issues.

4.2.5 Format and implementation of virtual workshops

Due to the Covid-19 pandemic, all of the workshops reported in Table 2-10 were operated as virtual events. This naturally reduces the degree of personal interactions that are otherwise enabled through physical meetings, whilst, in contrast, it generally allows higher participation from both presenters and delegates, since the additional constraints of travel are removed. Nevertheless, there is some reporting of user 'saturation' with such virtual events in general, the number of which has grown over the past year, 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.

Other, general observations on the implementation of virtual workshops, include the following:

- Full-day events place too much burden on participants, such that it is preferable to run workshops for somewhere between half- and three-quarter- (at most) day formats, ensuring sufficient screen breaks.
- Where thematically sensible, co-locating such workshops with another event works well and can help to drive up the attendance and range of participation at *both* events (a specific example is the virtual co-location of the Engage summer school and the fourth workshop of thematic challenge 2: 'AI, ML and Automation'.
- 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.
- It is important to secure expert discussants for panel and plenary session moderation; it inspires lower audience participation if the discussant/moderator is not able to maintain a sufficiently high level of technical interaction with delegates and participants.
- Mixing the content between highly specific material (e.g. a specialist area of cybersecurity) and very low TRL exploratory research is difficult to manage; careful alignment of the content of the workshop, the likely participants, and the objectives needs to be closely maintained.
- Circulating questionnaires in advance of a workshop met with mixed results, working well for some audiences and less well for others. A limited number of technical questions circulated to a technical audience seemed to work best.
- Mixing the internal format of workshops works well, for example between presentations, panel discussions and plenaries. *Simple* interactive boards (such as Retrospective) and in-line (*ad hoc*) polls work well with no pre-emptive training for participants required, and help to

maintain diversity across the workshop, in addition to offering an inclusive means of participation (e.g. for those who are more reticent to contribute orally).

- There was sometimes quite a diversity of participant numbers across similar events (e.g. Engage and non-Engage) organised over the period (e.g. regarding similar topics but divergent audiences). GDPR constraints permitting, it would be useful in SESAR 3 to consider a closer collaboration between projects and other (e.g. SJU) participant lists, to mutually drive attendance and support consistency of participation and homogenised learning and development across similar events, rather than separated streams of participants.

- The strong support from SJU regarding promotion of events through the SESAR *e-news* communications was much welcomed and highly beneficial. Communication of such events well in advance is advisable, with workshop organisers mindful of months whereby no *e-news* is to be issued.

- Across a number of platforms investigated, Zoom was the preferred option overall, giving a good range of functionality choices between its 'meeting' and 'webinar' modes, for example with regard to launching Q&As, *ad hoc* polls, and controlling webcam and microphone engagement. (It is to be noted, however, that *some* institutional firewalls may block Zoom access.)

- Applications (such as Zoom) that support (semi-)automated registration are also recommended, as this allows estimation of the number and demographics of likely participants and the management of (further) targeted invitations.

5 References

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6 Acronyms

ADS-B	automatic dependent surveillance – broadcast
ADSP	air data services provider
AI	artificial intelligence
ANSP	air navigation service provider
API	application programming interface
ATC	air traffic control
ATCO	air traffic controller
ATFCM	air traffic flow and capacity management
ATM	air traffic management
ATS	air traffic services
AU	airspace user
AWA	adverse weather areas
AWOS	automated weather observing system
CDO	continuous descent operations
CDA	continuous descent arrival
CF	catalyst fund(ing)
CNS	communication navigation surveillance
CONOPS	concept of operations
DCB	demand capacity balancing
DOI	digital object identifier
DoS	denial of service
ENV	environmental
ER	exploratory research
EWS	early warning system
FDP	flight data processing
FL	flight level
FMP	flight management position
FMS	flight management systems

GDPR	(EU) General Data Protection Regulation
GNSS	global navigation satellite system
HMI	human machine interface
IR	industrial research
KPA	key performance area
KPI	key performance indicator
KTN	knowledge transfer network
MET	aviation meteorology
ML	machine learning
NM	Network Manager
R&D	research and development
RAD	route availability document
RDT	rapidly developing thunderstorm
SAF	sustainable aviation fuel
SDN	Software defined network
SES	Single European Sky
SES II+	second regulatory package of the Single European Sky
SESAR	Single European Sky ATM research
SJU	SESAR Joint Undertaking
SRIA	Strategic Research and Innovation Agenda
SSA	semantic similarity analysis
SWIM	system wide information management
TBS	time-based separation
TRL	technology readiness level
UAM	urban air mobility
UAS	unmanned aircraft system
USSP	U-space service provider
UTM	UAS traffic management
VFR	visual flight rules
VLD	very large-scale demonstration

Appendix A SESAR 2020 Experimental Approach guidance ER

SESAR 2020 Experimental Approach guidance ER

Edition date: **11 December 2020**
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Abstract

The purpose of the SESAR 2020 Experimental Approach Guidance is to propose to the Projects the best practices to consider when writing experimental approach/plan and when performing Experiments/Validation activities.

Table of Contents

1. Introduction

The objective of this guidance is to secure the application of scientific best practices when the Project defines its experimental approach. It provides guidance to the consortium members to facilitate the elaboration of an Experimental Plan. It also helps the projects to ensure that all key aspects are taken into consideration when designing the validation exercises and experiments. It complements the guidance provided in the SESAR Project Handbook.

The Experiment Plan should be drafted early in the project and be refined throughout the project. If possible, and for the benefit of the academic community, this plan should be public. Therefore, if no dedicated contractual deliverable was planned for the Experimental or Validation Plan, it could be integrated as an Annex into the Final Project Results Report. In agreement with the project, other suitable deliverables could be identified. In any cases, a dialogue with the SJU has to be initiated prior to the execution of the experiment.

1.1 Background

Following a set of recommendations raised by the Scientific Committee, the SJU would like to stress the importance of having a proper Experimental Plan (or Validation Plan), to be discussed and agreed with the SJU before the experiments or validation exercises take place.

In the context of SESAR development framework (Project Handbook) this plan is usually named „Validation Plan" for the IR projects and „Demo Plan" for the VLD projects. For the Exploratory Research projects, and in this paper, we will refer to it as the „Experimental Plan". An ER project can name it „Validation Plan" in case such a deliverable is already foreseen in the GA.

If possible, and for the benefit of the academic community, this plan should be public. Therefore, if no dedicated contractual deliverable was planned for the Experimental Plan, it will be integrated as an Annex into the Final Project Report so that it will be available to external readers when reading about the project results. In agreement with the SJU, other suitable contractual deliverables could be identified, in particular the Data Management Plan which is its companion. It should be prepared early in the project and be refined throughout the project.

1.2 Best practices recommendations

Projects should document their different alternatives in a balanced way, and depending on their research approach (hypothesis testing or searching for a solution), record the methodology and steps to be taken.

The plan will allow transparency and identify in particular the research questions, experiment objectives, hypothesis, methods, etc.

The objective of this guidance is to secure the application of scientific best practices when the Project defines its experimental approach. It consists of a checklist for the consortium members to facilitate the elaboration of its experimental approach. It also helps the projects to ensure that all key aspects are taken into consideration when designing the validation exercises and experiments. This guidance is intended to complement the guidance provided in the SESAR Project Handbook.

Please address the points below that are applicable to your research to initiate a discussion among the Project members, and the SJU will provide its feedback when assessing the related deliverable. You may always refer to other deliverables, to the proposal, to the PMP or to STELLAR repository for further details. However, as the Experimental Plan should also provide transparency to fellow researchers it is worth repeating some information in a dedicated Experimental Plan area/section that would otherwise be available only in non-public sources. It is recommended to provide Experimental Plan, to be defined at the beginning of the project, as an Annex to the Final Project Report, so that it is available to external readers when reading about the project results.

The SJU does NOT expect the Project to reply the following guidance in writing, the only expectation is that Projects refer to it during the preparation of the Experimental Plan and during the execution of the experimental activities, and discuss with the SJU in case of doubts/questions/clarifications.

The following sections provide both a proposed Table of Content for the Experimental Plan, and the expected content for each section.

2. Overview

Note: Here the project is expected to extract the relevant information from the GA, complemented by additional information when required.

The project is invited to consider the following points when characterizing/defining its experimental/validation approach:

- Make sure you have proper research questions. Research questions should be relevant, original, researchable, focused, and clear.
  - *It is anticipated that such questions are already clear in the Grant Agreement or defined before or during the Project kick-off meeting, nevertheless they also serve the purpose of providing transparency to fellow researchers that do not have access to the proposal or STELLAR. Therefore it is worth capturing the required information.*
- Make sure you have a clear idea of how your experiments contribute to the project's objectives. Usually a consortium may have objectives at project level and objectives at exercise level, which may not necessarily be the same. Here we are referring to the project level objectives as defined in the Grant Agreement.
- Make sure you have a clear idea of what is the basic set up and methodology of the research.
- Make sure you have a clear idea of which experiments are planned and how they are related to each other.
  - *Each project is expected to use STELLAR, which provides the possibility to capture these information; nevertheless, it is a good practise to make it clear in your documents, as experts not involved in the project don't have access to the project information on STELLAR.*

3. Objectives/General Approach/Methodology

It is anticipated that the below questions should have been already clarified during the kick-off meeting, and that either the project has an Experimental Plan/Validation Plan as defined in the GA or it has identified which deliverable will include it. The Experimental Plan should also contain an overview of the exercises planning, although it is recommended that this information will be reported in STELLAR as part of the process of preparing the Experimental Plan.

The following question may help to consolidate the development of the Experimental approach:

- Will your results be qualitative or quantitative (or both)?
- How will you validate your outcome (concept, system, tool, model, scientific finding, etc.)?
- Where is your experimental/exploration/validation/simulation exercise planning documented?
- Will you try to measure your concept impact with respect to several potentially competing Performance Areas? Will your research help improving the understanding of the associated trade-offs?[17]

[17] If possible, projects should refer to the Key Performance Areas as defined in the SESAR Performance Framework. However, exploratory research projects may also address Performance Areas that are not included in the SESAR Performance Framework.

4. Experimental/Validation Approach

When developing your experimental/validation approach, the following questions may be addressed:

- What is/are your (null/research) hypothesis/hypotheses? (if applicable)[18]
- Are there dependent, independent and control variables[19] in your research, and what are they?
- What are the reliability, sensitivity and validity[20] of your experiments or exercises?
- What are the key assumptions that may have an impact on the experiment's results?
- External validity: under which conditions can the results of your experiment or research be generalized and transferred to an operational environment? (e.g. environmental conditions, populations/demographics of users, traffic demand, traffic mix, external parameters, other assumptions, etc.)

- Do you have different (validation) scenarios? Is there a reference scenario? Is there a solution scenario? What are the differences between these scenarios?[21]

[18] Please note that in SESAR the terms "validation objective" and "success criteria" are usually used as defined and explained in the SESAR 2020 Requirements and Validation Guidelines. A hypothesis corresponds to a success criteria. However, to acknowledge that exploratory research project can be successfully even if a hypothesis needs to be rejected, this neutral term is used within this guidance.

[19] **Independent variables** are manipulated in an experiment. They are the cause of effects being measured. **Dependent variables** are tested and measured in an experiment. They are the effect. **Control variables** are kept constant in an experiment to prevent that they effect the dependent variables.

[20] **Reliability**: degree to which a test or an experiment leads to similar results when repeated under similar or identical conditions; **Sensitivity**: responsiveness to actual/modelled changes and assumptions (e.g. input parameters); **Validity**: degree to which the experiment permits correct conclusions about the environment it studies (includes statistical (conclusion) validity; internal validity and external validity

[21] In SESAR, the following definitions are used:

Solution Scenario: scenario including traffic and operational environment and SESAR operational improvements that is the subject of the validation.

Reference Scenario: Scenario including traffic and operational environment and without the SESAR operational improvements that are the subject of the validation, matched in time with the solution scenario.

Baseline Scenario: Common point of reference to be used by multiple validation exercises in order to perform measurements relative to a common, well-known and consistent origin.

All of these Scenarios are **Validation scenarios.** These terms should be used when applicable. However, as the nature of the experiments performed by exploratory research projects may not have the nature of a validation and as exploratory research project do not have assigned solutions, this might not always be the case.

- What statistical tests will you be applying? What is their significance level and how will they be set? What software will you use for statistical evaluation?
- Will you run a pre-experiment, or a pilot run? If so, what is the set up and methodology for this? How will lessons learned from this process formally be incorporated into the experiment?
- How many iterations do you plan for the concept development in your project? Do you plan to perform several development cycles to refine concept and results?
- Is a description of the experiment(s) equipment publicly available? (e.g. set up & environment, software used, user interface, etc.) ?
- Is the Project proposing new (or addressing existing) Operational Improvement Steps (OIs) and/or Enables (ENs) linked to their research?[22]
- Will you define and develop new Performance Indicators or adopting existing KPIs ?

… if your experiment involves human in the loop (HITL) simulations

- What are the potential sequence effects (such as fatigue, learning, carry-over, maturation, reactivity) and how will your experimental/factorial design ensure you avoid them (e.g. Latin square, randomization, pseudo-randomization)?
- If you are running an experiment, how many test subjects are you planning to include / how big is the sample? How do you estimate the required sample size?
- Which specific participants/respondents (demographics, expertise, characteristics) do you need?
- How will you recruit/sample the participants/respondents?

… if your experiment involves model-based or fast-time simulation exercises

- Are the planned simulations stochastic or deterministic? Will you model uncertainties, disturbances and disruptions? How?
- Will you assess emergent behaviour?
- Will you perform rare events simulation?

[22] **OI Step:** The elementary level of an operational improvement (any operational or action taken through time in order to improve the current provision of ATM operations)

Enabler: New or modified technical system/infrastructure, human factors element, procedure, standard or regulation necessary to make (or enhance) an operational improvement.

See EATMA Guidance Material in Programme Library on Stellar for more information

… if you are planning field studies, shadow-mode trials or observations

- Do you have a reference scenario? What is the reference scenario?

… if you are using questionnaires

- Are you using validated questionnaires/scales or designing your own questionnaire?
- Do you plan to use open-ended responses? How will you analyse them?
- Did you plan appropriate statistical tests determined by the scalar format of the question (e.g. categorical / ordinal / interval; dependent / independent; even vs. odd number of items on Likert scale)?
- Have you tested the questionnaire (in case you are designing your own questionnaire)?
- How have you determined the required sample size and (unbiased) sampling method?
- If you are carrying out ‘before’ and ‘after’ surveys, have you accounted for sample attrition?
- How will you analyse the responses?
- Which (dependent and independent) statistical test(s) will you use?

5. Data and software Input

It is anticipated that most of the questions below are already or will be answered in the Data Management Plan (DMP) deliverable. Nevertheless, since the DMP might be a Confidential deliverable or the Project may not have it in the list of contractual deliverables, it is worth to consider and document the following points when designing an experimental activity:

- What are your data needs? What type of data sets do you need for your research? (e.g. flight plan data, radar tracks, delay data, cost data, passenger itineraries, validated schedule data)
- How will you obtain these data sets?
- How will you process/clean these data sets?
- Will you use open data sources?
- Do you have sufficient finances for data procurement? If insufficient, what would be your alternatives?

Data output and recording

- In which format will you record the output of your experiments (video data, file logs…)
- Which post-processing, if any, is required?
- How will you analyse the output data? Which statistical test(s) will you use? How does the output data set allow you to address the hypotheses of your experiment and/or the research question(s)?

6. Research coordination and development

It is anticipated that most of the points and questions below are already or will be answered in the Data Management Plan (DMP) deliverable and discussed during the kick-off meeting. Nevertheless, since the DMP might be a Confidential deliverable or the Project may not have it in the list of contractual deliverables, it is recommended to consider and document the following points when designing an experimental activity:

- The consortium should make sure that the research data management has been planned (e.g. Storage, Security, and Access during data lifecycle).
- If you plan to disseminate results by means of a scientific publication, do you also plan to make the underlying research data available? This is of particular relevance if the project participates to the H2020 open research data pilot.

Furthermore, the following questions should find clear answers before starting the experimental activities:

- What would be necessary to reproduce the results?
- Would another researcher be able to reproduce them?
- Do you plan to make your source code open to facilitate reproducibility ?
- Are data, methodology descriptions, software available and public for this purpose? If not, why not?

7. And now some references

1. EUROCONTROL Data Portal, https://www.eurocontrol.int/dashboard/rnd-data-archive

2. EUROCONTROL, European Operational Concept Validation Methodology (EOCVM), Version 3, 2010, Volume 1: https://stellar.sesarju.eu/jsp/project/qproject.jsp?objId=17966057.13&resetHistory=true&statInfo=Ogp&domainName=saas, Volume 2: https://stellar.sesarju.eu/jsp/project/qproject.jsp?objId=17966105.13&resetHistory=true&statInfo=Ogp&domainName=saas

3. SESAR 2020 Requirements and Validation Guideline, https://stellar.sesarju.eu/jsp/project/qproject.jsp?objId=18783871.13&resetHistory=true&statInfo=Ogp&domainName=saas

4. PJ19: EATMA Guidance Material and Report, https://stellar.sesarju.eu/jsp/project/qproject.jsp?objId=20855624.13&resetHistory=true&statInfo=Ogp&domainName=saas

5. Regarding pre-registering experiments and hypotheses, *inter alia*, researchers may refer to the Open Science Forum (www.osf.io)

6. Regarding survey design and analysis, Tull and Hawkins, *Marketing Research – Measurement & Method* (6th Ed.) (Macmillan), is an excellent reference

7. Frank and Althoen, *Statistics – concepts and applications* (Cambridge University Press), is very good on detailed application of stats testing

8. https://apastyle.apa.org/style-grammar-guidelines/paper-format

Appendix B Wiki features, further details and links

Wiki activity / page name	Short description	Further information in D3.9:	Link to active wiki page
Interactive research map	Interactive research map visualisation where users can explore the results of a bottom-up clustering from unsupervised machine learning applied to SESAR 1 and SESAR 2020 projects and papers	Section 3	https://wikiengagektn.com/EngageWiki:Interactive_research_map_of_ATM
ATM concepts roadmap	Interactive roadmap that shows how previous (SESAR) research connects with the flagship activities of the 2020 Strategic Research and Innovation Agenda, and identifies future challenges	Section 4	https://wikiengagektn.com/EngageWiki:ATM_concepts_roadmap
Discussion fora	Discussion fora for common interest research communities. Open to all registered users	Section 5	https://wikiengagektn.com/Special:WikiForum
European university programmes	Interactive database of undergraduate (UG) and postgraduate (PG) programmes offered in Europe; features UG courses related to air transport engineering and aviation management and PG courses that perform ATM-related research; user-updateable	Section 6	https://wikiengagektn.com/EngageWiki:Programmes
Teaching resources	Three introductory courses that are available for use by any (academic) institution, free of charge, via a registration process hosted on the EngageWiki	Section 7	https://wikiengagektn.com/Teaching_Resources
Research repository	One-stop, go-to source for information: a single European point of entry for ATM knowledge. With improved search functionality and accessible meta-source of research data	Section 8	https://wikiengagektn.com/EngageWiki:Research_repository
PhD funding opportunities	Open PhD funding opportunities. Open to registered users to add new opportunities	(Various sections)	https://wikiengagektn.com/EngageWiki:PhD_funding_opportunities
Jobs and internships	Vacant job and internship positions. Open to registered users to add new vacancies	(Various sections)	https://wikiengagektn.com/EngageWiki:Jobs_and_internships

Appendix C Gap analysis: top 20 unique projects

WBS	Acronym	Project name	Description
E.01.02	HALA!	Higher Automation Levels in ATM	The main objective pursued by the "research" into "Higher Automation Levels in ATM" is to explore unconventional and high risk areas, involving new technologies and concepts around the theme "Toward higher levels of automation" in future Air Traffic Management Systems. The Research Network activities to support the achievement of these objectives are: • Interaction with worldwide experts from multidisciplinary research environments. • Coordination with worldwide ATM experts. • Funding PhDs programmes at leading European Universities. • Organization of meetings, workshops and conferences to raise the awareness on the research conducted . • Development of a "Position Paper" reflecting strategic principles to foster the research on automation in ATM. • Coordination with SESAR funded R&D projects on related topics.
E.02.06	POEM	Passenger-Oriented Enhanced Metrics	At the core of POEM (Passenger-Oriented Enhanced Metrics) is the design of new performance metrics and the evaluation of these through a European network simulation model under novel flight and passenger prioritisation scenarios. Key objectives were to explore the trade-offs between the (new) flight-centric and passenger-centric metrics and to characterise the propagation of delay through the network. POEM concluded that simple flight prioritisation rules, e.g. based on passenger numbers, were ineffective; that policy-driven rules only made an impact when current airline constraints were relaxed; that airline cost minimisation rules resulted in win-win outcomes. Furthermore, that passenger-centric metrics are needed to see the full impacts of operational change and that reactionary (knock-on) delay in the network accounts for almost half of all delays in Europe – these effects have been better characterised by the POEM analyses.
E.01.01	ComplexWorld	Mastering Complex Systems Safely	ComplexWorld is a Research Network that was created to lead the long term research needs of SESAR (Single European Sky ATM Research), one of the European Commission's most ambitious research and development projects. SESAR is a results-driven initiative with the aim of meeting future air capacity and safety needs while building the European economy on strong foundations of knowledge, research and innovation. Work Package E, the Long Term Research vehicle of SESAR, sets out to explore four areas of exploration, one of which is 'Mastering Complex Systems Safely'. The ComplexWorld Network is specifically tasked with addressing this theme and with establishing how Complexity Science can contribute to understand, model, and ultimately drive and optimise the behaviour and the evolution of the ATM system that emerges from the complex relationships between its different elements. As an open partnership between universities, research centers and industry, ComplexWorld's objective is to: • Provide a structured forum for the development, exchange and dissemination of research knowledge in ATM Complexity Management • Lower the barriers for the ATM community to have access to and benefit from Complex Systems science • Attract talented Complex Systems researchers towards ATM.

WBS	Acronym	Project name	Description
			• Foster the interaction and ideas sharing between the Air Transport and the Complex Systems research communities • Define, develop and maintain a clear roadmap for establishing and consolidating a research community at the intersection of Complexity and ATM of clear added value for the European Air Transport sector.
01.09	WE FREE	WE FREE	Executive summary the WE-FREE demonstration scope was defined as en-route optimization mainly in the lateral dimension, with possible vertical optimization as well, for flights departing from Paris CDG airport and having a destination in Italy during weekend operations. as so, we free project is an instantiation of the SESAR project p7.5.3 called user preferred routing in a high traffic density area. The focus areas addressed by the WE-FREE project are the free routing (ofa 03.01.03) and the trajectory management framework (ofa 03.01.01). to manage this project, we free consortium is composed of: 3 ANSP, two OF FABEC DSNA and Skyguide and ENAV 4 airlines: Air France, Alitalia, hop! those seven partners worked together to design new strategic planning of cross border direct between cdg and italian destinations (i.e. fco, nap, vce, lin, trn, vrn, blq, goa, psa) and evaluate the feasibility of their implementation. the project studied in particular the feasibility to design those directs from sid exit point to star entry point. two trial week-ends were run in november 2013 and the feedbacks of all partners were very positives. the project showed that, thanks to we free routings, 925 nm, 140 min, 6,5 tons of fuel, 20 tons of co2 could be saved per day and that there is an horizontal deviation reduction of 1% compared to the current horizontal deviation. enav, skyguide and dsna reims are studying the implementation of we free routes with a step wise approach. for the moment, a winter implementation is foreseen for most of the routings. this option is strongly supported by the AO
699221	PNOWWA	Probabilistic Nowcasting of Winter Weather for Airports	The principal PNOWWA result is the probabilistic radar-based nowcasting of winter weather, which will enable the estimation of winter weather conditions affecting the ground part of air traffic 4D trajectories. When applied to ATM applications and services, our method will enhance timely operations in surface management and ATM decision making. It can decrease the effects of adverse winter weather to airport procedures and by that it will increase airport resilience, shorten delays and will also maintain safety of airport functions during winter weather cases. PNOWWA has developed and demonstrated the benefits of the very short-term (0-3h nowcast) probabilistic winter weather forecasting method, which is based on identification and extrapolation of the movement of weather radar echoes with 15min time resolution. The benefits of the PNOWWA nowcasting method were shown through two research demonstrations that were conducted both offline and online at Operative User Environment (OUE) sites at the airports of Innsbruck and Helsinki, representing the influence of the underlying terrain to forecast accuracy. An extensive user consultation survey among a number of airports and ATM stakeholders was performed to ensure the forthcoming products are suitable to be integrated in various applications on the ATM side. Based on the survey, majority of stakeholders see most potential for probabilistic weather forecasts to help render decisions objectively, and secondly by using them in decision support when cost-loss ratios are known. The achievements gained in PNOWWA contribute to all the SESAR Key Performance Areas except to 'Security'. The ATM Key Feature, which benefits mostly from PNOWWA is 'High-performing airport operations'. Based on the maturity analysis performed for PNOWWA project, it can be concluded that the PNOWWA project belonging to the Enabler METEO-04d has reached the maturity represented by Technology readiness Level 1 (TRL1 INTERMEDIATE). During the PNOWWA development process, needs to update the Enabler METEO-04d were found and update of the METEO-04d were

WBS	Acronym	Project name	Description
			suggested. The PNOWWA project roadmap towards implementation has connection points in future SESAR projects. The PNOWWA methodologies that were developed utilizing probabilistic radar-based nowcasting and tested in actual operational ATM environment need to be brought up to higher TRL levels (next TRL2) for the benefit of ATM stakeholders and their operational activities.
E.02.28	TREE	Data-driven Modelling of Network-wide Extension of the Tree of Reactionary Delays in ECAC Area	The reactionary‘, 'knock-on' or 'propagated’ delays are one of the largest delay causes in Europe. The Reactionary delays have no specific origin or cause, they result from primary delays transferred from a previous flight through aircraft rotation, crew links and passenger connections. The share of reactionary delay out of total delay reaches 40 %. Flight links through the use of constrained resources are the mechanism for the propagation of delays and the amplification of the impact of root delays in the flight network. Airlines related causes are the ones with highest contribution to the total delay (CODA Digest 2012 report). It is complex and difficult for airlines to record successfully the precise origins of reactionary delays. The way airlines handle primary delay disruptions determines the extent and pattern of the knock-on effect. TREE will apply modelling and simulation to predict the occurrence of the reactionary delays in European Civil Aviation Conference (ECAC) area. Also TREE will characterize the propagation of reactionary delays taking into account the influence of the aircraft, crew and passenger links, evaluate the daily planning performance and analyse the impact of perturbations in the network and then test the implementation of diverse airline disruption management measures from the ATM Network and Airlines points of view. Additionally new metrics will be defined, inspired in Complex Networks Theory to quantify the level of Air Transport Network congestion. The proposed metrics of performance will have different levels of resolution, from local or airport based to regional or network-wide. Thus, the model will allow the evaluation of a daily planning performance as well as assessment of the impact of perturbations in the network. The model structure and its functionalities will also make possible the exploration of the limits of the present theories in Complex Networks regarding Air Transportation system stability and control of the networked dynamic. TREE is expected to develop and validate a model able to: • Process large amount of flight data including aircraft, crew and passenger links; • Forecast propagation patterns of reactionary delays; • Capture network response to the introduction of large-scale disruptions and the level of uncertainty; • Represent and analyse delay management solutions at strategic planning level and their influence on the delay propagation. To this end, new concepts and methods will be implemented in software tools with the aim of describing in a realistic way the propagation of delays throughout the European Air Transportation Network. In addition new metrics of performance will be proposed in order to attempt quantifying the level of Air Transport Network congestion.
699274	COPTRA	COmbining Probable TRAjectories	COPTRA proposes an efficient method to forecast air traffic probabilistically by using flight trajectory predictions within a Trajectory Based Operations (TBO) environment. This objective is detailed with three sub-objectives that form three research work packages: • Define the concept of probabilistic trajectory prediction (WP02). • Define the probabilistic traffic concept and study how it can be constructed by combining probabilistic trajectories, using the probabilistic trajectory definition (WP03).

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WBS	Acronym	Project name	Description
			• Apply probabilistic traffic to Air Traffic Control (ATC) planning (WP04). COPTRA addresses a very specific aspect of TBO related with the ability to help demand-capacity as well as traffic planning through the identification and management of prediction uncertainty (both at trajectory and traffic levels) as expressed in the S2020 advanced Demand & Capacity Balance (DCB) concept. The added value that this deliverable brings into the SESAR 2020 programme is mainly the provision of a probabilistic trajectory predictor and a traffic uncertainty propagation framework to the S2020 PJ09.01 “Advanced Demand and Capacity Balance”, including an assessment of how integrating trajectory uncertainty models into existing tools. Furthermore, a project added-value output will be the provision of traffic prediction based on probabilistic traffic situations to S2020 PJ09 (Network Prediction and Performance). The scope of the COPTRA is to propose an efficient method to build probabilistic traffic forecasts based on flight trajectory predictions within a TBO environment. This objective can be detailed as defining and predicting the concept of probabilistic trajectories (WP02), defining the concept of probabilistic traffic situation by using probabilistic trajectory definition, studying how probabilistic traffic situations can be built by combining probabilistic trajectories (WP03) and applying probabilistic traffic situations to ATC planning (WP04).
763551	CORUS	Concept of Operations for EuRopean UTM Systems	A harmonised approach to integrating drones into very low-level airspace is vital if the rapidly growing drone industry is to fulfil its economic and social potential. Gathering experts from aviation, research and academia, guided by a 21-member stakeholder advisory board, the CORUS consortium developed a Concept of Operations (CONOPS) for U-space. It proposes an initial architecture for this airspace with a detailed definition of the airspace types to be used for very low-level drone operations and the services in them, so that operations are safe and efficient. It balances the needs of the drone sector with those of society as a whole. The activity of the CORUS project centred around three workshops held in January and June 2018 and April 2019, each attended by 100 stakeholders of widely varying backgrounds. Each workshop discussed a new iteration of the CONOPS, allowing the project to refine and validate them, leading to a U-space concept of operations (edition 3), providing the latest baseline for the U-space services. The CONOPS details drone operations in uncontrolled very low-level airspace, and in and around controlled and/or protected airspace such as airfields. It also describes an initial architecture that identifies the airspace types, services and technical development necessary for implementation of the CONOPS, quantifying the levels of safety and performance required. It includes use-cases for nominal scenarios such as contingencies and emergencies; and proposes a method to assess the safety of service provision (MEDUSA). Finally, it proposes solutions for easing social acceptance of drones by examining aspects including safety, privacy, noise and other societal issues. The CONOPS is a living document and so the expectation is that updates will be required in order to take into account the evolution towards urban air mobility (UAM) operations.
E.02.29	ACCESS	Application of Agent-based Computational Economics to Strategic Slot Allocation	The project addresses demand and capacity management at congested airports, focusing on market-based mechanisms for the strategic allocation of airport capacity. Market mechanisms are expected to provide the right incentives for a more efficient use of the available capacity, but they also raise a number of concerns, from the potentially negative impact on airline operating costs to cases of market failures. There is therefore, a need for a comprehensive assessment of different market designs for slot allocation. In this project there are some considerations about the conditions to be met by a performance framework to allow a sound comparative evaluation of different slot allocation mechanisms, that outline a preliminary proposal for a set of performance areas and indicators,

WBS	Acronym	Project name	Description
			and discuss the potential impact of different possible reforms of the slot allocation system. The project will propose a set of indicators aimed at covering each performance area in an objective and measurable way, and we discuss the potential impact of different possible reforms. Far from being exhaustive and definitive, the project represents a first approach aimed at conveying some general reflections with a view to establishing a comprehensive framework for performance assessment. It is expected that further steps will be required to involve completing and refining the proposed framework through: (i) consultation with stakeholders, (ii) formalization of several market approaches to airport slot allocation, (iii) development of a simulated test bed based on agent-based computational economics to evaluate the proposed market designs along the specified performance areas.
763702	PercEvite	PercEvite - Sense and avoid technology for small drones	PercEvite has developed a sensor, communication, and processing suite for small drones, enabling detect-and-avoid of ground-based obstacles and flying air vehicles without necessitating human intervention. In the project, we have made two such suites, a minisuite (~150 grams) and a micro suite (~50 grams). Both suites include the capability to avoid ground-based obstacles and perform cooperative avoidance via WiFi. LoRa, and LTE. The mini suite additionally has ADSB-in for avoiding general aviation aircraft equipped with ADS-B. While the mini suite is completely based on commercially of-the-shelf products, the micro suite includes a stereo vision system that was custom- designed in PercEvite. We will release the schematics of this stereo vision system under an open hardware license. Besides the creation of the PercEvite mini and micro suite, we have also developed various algorithms for achieving avoidance of ground-based obstacles, communication-based cooperative avoidance, and different manners of non-cooperative avoidance. Many of these algorithms have been successfully tested in real-world environments. Our investigation has led to the following four conclusions. First and foremost, it is possible to create very light-weight suites for staying well clear of both static obstacles and other flying air vehicles, requiring minimal adjustments to current hardware and software used by drone producers. Second, communication of position and velocity between different flying air vehicles is very mature and can be implemented with little effort at a very high gain. Third, ground-based obstacle avoidance is also rather mature, although limitations (flying in the dark, fog) and edge cases (reflections, transparent surfaces, etc.) exist. These limitations and edge cases can be tackled though by additional sensors if necessary. Fourth, although we made important steps towards non-cooperative sense and avoid, it is the least mature technology. In PercEvite we have observed that it mostly suffers from the availability of data sets for (1) benchmarking performance, and (2) machine learning. Our main recommendation to advance sense-and-avoid technology is for SESAR to set up a call for the creation of big data sets for non-cooperative sense-and-avoid, with the aim of making the data open access for use by the community. The call should in our opinion be open to different data types, as explored in PercEvite (audio, visual, radio frequency (RF), etc.).
699387	NAVISAS	Navigation of Airborne Vehicle with Integrated Space and Atomic Signals	NAVISAS investigated multiple constellation satellite positioning systems with miniature atomic clock (MAC), miniature atomic gyroscope (MAG) and vision-based navigation. The project analyzed several paths for technology mergers for applications in small aircraft navigation, in particular: (i) standalone high grade inertial navigation system (INS) based on atomic gyros, (ii) hybridized multi-constellation multi-frequency system coupled with high grade INS, and (iii) vision-based navigation. The research included extensive literature review on performance based navigation documentation and clarified the relevance of specific PBN aspects to small aircraft operations. The TRL of atomic gyroscope reached TRL3 in the scope of NAVISAS. Envisioned performances are promising and could

WBS	Acronym	Project name	Description
			challenge currently used high grade laser gyros. Several solution at the system level have been developed to reduce the price of the entire IMU system combing 3 axis gyros, accelerometers, GPS /GALILEO /GLONASS and atomic clock for application in UAV and ULA. Hybridization of multi-constellation multi-frequency GNSS coupled with high-grade INS has been assessed. No real benefit could be seen from the use of multi-frequency receivers when compared GPS L1 signal, nevertheless they are a good backup mean in case of unintentional interference on one GNSS frequency. Multi-constellation GNSS tight coupling with INS is an interesting approach for scenarios with frequent GNSS outages. Purely inertial performance of high-grade INS based on atomic gyros is expected to reach the one from currently used laser gyros. GNSS coupling with INS is already used in commercial aviation. GNSS hybridization with INS-based on atomic gyros achieved TRL3 in this project. Vision-based navigation was assessed in real flight and showed good performances for RPAS navigation and light aircraft as well. It is expected to become a standard for RPAS in the coming years. The proof of concept was delivered and TRL2 was achieved.
E.02.22	NINA	Neurometrics Indicators for ATM	NINA is a research project co-funded by SESAR, as part of its long term research programme. It aimed at developing a tool able to perform a real time assessment on a set of cognitive states of Air Traffic Controllers performing their job – such as mental workload intensity, type of attentional control and proficiency level gained during a training period. The tool uses an algorithm based on the analysis of 3 main neurophysiologic indexes: electrical brain activity, heart rate variability, eye blinking. As an integral part of the project, a study to show how the further development of similar kinds of tools could enhance aviation safety and efficiency was performed. This page briefly summarises the results of the study, presenting a proof-of-concept for an advanced system able to understand in real time the operator's psycho-physical state, to match it with the situation in which she is operating and to provide the best automated support accordingly.
699382	TaCo	Take Control	Automation is one of the key solution proposed and adopted by SESAR to tackle the challenges coming from the increase of capacity and complexity of the future ATM system, including airports. The main contribution of TaCo project is a framework for design, development, verification and future implementation of automated tools for airports with the involvement of end-users since the beginning (end-users programming of airport surface movements management). TaCo framework gives the controller the possibility of instructing automation with the rules, procedures and working methods that actually support his/her everyday work. This is done by means of an interactive platform (user programming editor) that enables the definition of rules, procedures and working methods related to the management of surface movements in complex airports. The proposed approach gives the opportunity to tower ATCOs to program and test automation (and their interaction with it) based on their operational needs and using a simple visual language. This approach, opposed to a "traditional" engineering cycle where operational needs must be translated into functional requirements and then coded, tested and validated, reduces the risks of "lost in translation" and increases the efficiency, suitability and usability of automation. One of the main enablers for a fruitful collaboration between the end-user and the automation is the definition of operational strategies and related automation strategies (algorithms). The development of innovative algorithms for the optimization of routing paths and departure/arrival sequencing or for the minimization of fuel consumption are out of the scope of TaCo. On the other hand, the study of interactions needed to apply a certain strategy (or switch from one strategy to another under certain circumstances) in a hybrid human-automation system is one of the activities of the project. The evaluation of TaCo's framework

WBS	Acronym	Project name	Description
			involved both Malta International Airport (MIA) tower controllers (end-users) and external stakeholders coming from the airport domain during two distinct workshops. Results show positive feedback from end-users as well as from external stakeholders. The introduction of automation strategies as the main support for handling the operations was considered beneficial and additional promising strategies were identified during the evaluation. Furthermore, such strategies were not only perceived as a support for optimization, but more in general, as an assistant for coping with specific situations. TaCo contributes to the definition of a new SESAR Operational Improvement (OI) with the following outcomes: • A framework for design, deployment and verification of automated tools for airports with the involvement of end-users (tower ATCOs) since the beginning (end-users programming of airport surface movements management) • An approach to enhance the visibility of the level of automation in the tower environment and mitigations measures of transitions among different levels of automation support (towards visibility, awareness, transparency); • Design guidelines for designers of similar hybrid human-automation environments and for designers of automation in such environments: o Continuum of usage and progressive disclosure o Space-based and event-based constructs o Make current state and future behaviour visible o Seamless AND seamful hybrid control
E.02.27	SCLOUD	SecureDataCloud	SecureDataCloud provides a new paradigm to deal with confidentiality issues without limiting the ability of performing relevant computation of private data: the use of secure computation techniques. The use of secure comptutation would enable the improvement of data-intensive applications within Air Traffic Management, starting with actual research activities. Among others, these include safety, allowing analysts to mine some specific pattern inside historical data, without actually accessing the data sets and thus ensuring confidentiality; understanding global properties of air transport, as for instance the number of passengers in a given route, or actual fuel consumptions; or improving the cooperation between airlines, fostering mechanisms such as slot bidding. SecureDataCloud aims at providing general guidelines for the application of secure computation techniques as well as proposing the means ofg applying those guidelines to support different business needs. SecureData Cloud also aims to create a Software Reference Framework, providing functions, algorithms and protocols that will constitute the starting ground for anyone beginning a new development.
783170	GRADE	GNSS Solutions for Increased GA and Rotorcraft Airport Accessibility Demonstration	"The project main objective is the demonstration of General Aviation and Rotorcraft capability to benefit from the concepts developed in the SESAR programme, in order to facilitate their integration into airspace and airports where the SESAR concepts and technologies are implemented. This objective will be achieved through live flight trials and preparatory Real-Time Simulation campaign, with hardware and humans in the loop, which will be focused on both procedural issues and technological aspects related to Global Navigation Satellite System technologies and simultaneous non-interfering operations. Specifically, the GRADE project will demonstrate in flight, by using GA aircraft and Rotorcraft equipped with non-certified or specific on-board equipment, the following existing SESAR Solutions: Solution #51 – "Enhanced terminal

WBS	Acronym	Project name	Description
			operations with LPV procedures", Solution #55 – "Precision approaches using GBAS CAT II/III", Solution #103 – "Approach Procedure with vertical guidance", Solution #113 – "Optimised Low Level IFR routes for rotorcraft". The project will also focus on technological aspects, testing in flight the following products, already available within the consortium and suitably customized to fit the above listed SESAR Solutions: GNSS EGNOS and GBAS navigation algorithms able to guarantee the applicable RNP; Portable non certified Primary Flight Display to support pilot decisions and operations. The live flight trials will be conducted at two different sites and using three different aircrafts (two fixed-wing and one rotary aircraft). Flight tests data and information will be collected and analysed by taking into account relevant applicable SESAR Key Performance Areas and suitably performance indices. Performance evaluation and lessons learnt will represent the outcome of the project and will be made available to support regulation, standardisation and certification activities, as well as the integration of GA and rotorcraft with commercial aviation."
E.02.25	Sixth Sense	Increasing Fault Tolerance of Human Machine Interfaces through Sensor Fusion	Safety critical systems in general and ATM systems in particular are designed according to the highest safety standards. The 6th Sense project will concentrate on improved fault tolerances of the human machine interface by accepting the overall user's body language as input. This means that we want to make use of multiple sensors and actuators, e.g. mouse, pen, eye tracking, gesture recognition, and overall system information, and fuse these into one most likely interaction, eventually, supported by a decision workflow system to judge different possible meanings of the interaction. The 6th Sense module will support the operator by offering the first steps towards a more holistic solution for multimodal user interaction. The theory will be proven by the software module prototype "6th Sense" that could be implemented into every CWP prototype for improvement of failure tolerance in the Human Machine Interaction. Within the 6th Sense project the objective is to have an integrated solution for multimodal user interaction. The 6th Sense module will be a central Human Machine Interface (HMI) abstraction layer. With a global view on the heterogeneous input data, it will be possible to analyze the typical workflow of an ATM user. With methods of signal processing, signal fusion, machine learning, among others, the new HMI module will aim to record, analyze and classify human interaction.
09.27	-	Multi-constellation GNSS Airborne Navigation Systems	The main objective of Project 9.27 was to study the next generation of multi-constellation GNSS receivers (MCR) for improved navigation performance: this includes support to standardization, technical studies and prototyping of Galileo/GPS equipment. Project 9.27 also supported studies related to hybridization of GNSS with low-cost inertial systems. In a first step, the efforts focused on the specification of Galileo/GPS airborne equipment with Aircraft Based Augmentation System (ABAS) and Satellite Based Augmentation System (SBAS) capabilities, either for mainline and regional aviation or for business and general aviation. In parallel, several studies have been launched to: • Evaluate possible analogue and digital technologies for the development of future MCR products; • Assess for ABAS the performance of the new generation of Advanced Receiver Autonomous Integrity Monitoring (ARAIM) algorithms using multi-constellation signals, in particular for lateral navigation (Horizontal ARAIM or H-ARAIM); • See the potential benefits of integrating low-cost inertial sensors in future navigation systems. Based on the specifications elaborated during the first phase, the developments of two MCR mockups have been launched, one for Mainline / Regional Aviation, and a second for Business / General Aviation, plus software MCR Simulation Platform (MRSP). The

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WBS	Acronym	Project name	Description
			simulation platform aimed at studying different multi-constellation features (such as fusion and advanced integrity concepts), using observables and navigation data as inputs, e.g. from RINEX files of true data. The mock-ups assessed the readiness of technologies for future MCRs, and provided to the standardization working groups feedback on the use of Galileo and modernized GPS signals, and on the different functioning modes of the MCR (nominal and degraded). Additionally, the mock-ups were tested with respect to the procedures drafted in the Minimum Operational Performance Standards (MOPS) [4], which allowed maturing the proposed tests. At the end of the project, the level of maturity reached for MCRs is deemed to be TRL 4, since most of the technology components have been validated in a laboratory environment.
12.04.07	-	Remotely Operated Tower Multiple Controlled Airports with Integrated Working Position	The purpose is not to answer how a remote/virtual tower is implemented nor to describe a specific solution, but to describe on a general level the functionality such a solution must provide in order to fulfil the operational methods and scenarios described in the OSED. The purpose is also to provide a requirement description that fulfil the operational and functional requirements, and that can be used by stakeholders to procure a specific implementation. The OSED describes three new SESAR operational methods, all addressed from a technical perspective in this document: • Remote Provision of Air Traffic Services for a Single Aerodrome; o P12.04.07 has developed three platforms, that have been validated by P06.09.03 • Remote Provision of Air Traffic Services for Multiple Aerodromes; o P12.04.07 has developed three platforms that have been validated by P06.09.03 • Remote Provision of Air Traffic Services in Contingency Situations at Aerodromes o P12.04.08 has developed three platforms The main change in the new operating methods is that the ATCO of AFISO will no longer be located at the aerodrome. They will be re-located to a Remote Tower Module, often co-located in a Remote Tower Centre. The views of the aerodromes are then visually reproduced in the Remote Tower Module using either Remote Tower technology (live video capture using cameras) and/or Virtual Tower technology (3D models supported by surveillance data). This document will not cover the virtual tower concept in any depth, since no validations have been made on that platform. The content of this document will be based both on experience from previous projects as well as a series of P06.09.03 remote tower validations within all three mentioned operational applications. In the final version of the document relevant requirement is updated with configurations and hardware parameters used in platforms in different validations. This makes it possible to look in to validations results using the different validations reports (VALR) for each validation.
08.03.10	-	Information Service Modelling deliverables	Project 08.03.10, Information Service Modelling deliverables, has delivered one of the main elements of the SWIM concept [4] (System Wide Information Management), for the European ATM community by producing a well-tested ISRM (Information Service Reference Model) Foundation with rules and guidelines for the design of logical services together with the Information Service Reference model, ISRM, consisting of a portfolio of 40 designed logical services The SWIM concept is a key enabler to achieve the high-level goals of the SES (Single European Sky) through promoting enhanced interoperability on different levels. This is a paradigm shift of Information Management done by standardisation of information, information exchanges and all the related governance activities. The services in the ISRM ensure operational and semantical interoperability through standardisation. Project 08.03.10 has made major contributions to the definition and development of the SWIM concept and the introduction of service orientation in the SESAR programme. This included the settlement and definition of service

WBS	Acronym	Project name	Description
			orientation in the programme through the document "Service scope and approach" [5], and supporting the definition of a programme wide development process for services in the document "Working method on services" [6]. This process was then applied in the P08.03.10 Fast track initiative where architectural-, operational-, SWIM- and system projects worked in coordination to develop the defined artefacts throughout the service life cycle. The fast tracks were later on formalised in service activities governed through a programme wide coordination forum called the SCG (Service Coordination Group). The establishment of the SCG and the de
10.02.05	-	Flight Object IOP System Requirement & Validation	The main project objectives were: • Demonstrate the suitability of the Flight Object to implement the SESAR Reference Business Trajectory within the En-Route and Terminal Manoeuvring Area domains. • To provide prototypes to support the validation of the Operational Improvement regarding to the (initial Reference Business Trajectory) Agreed Reference/Mission Trajectory through Collaborative Flight Planning and the Operational Improvement Automated Assistance to Controller for Seamless Coordination, Transfer and Dialogue. • To provide deliverables to support the implementation of ground-ground flight data exchange between Air Traffic Control units through the use of Flight Object services as defined by the Flight Object in EUROCAE Ed.133 [44] inside the Operational Focus Area related to the Trajectory Management Framework and System Interoperability with air and ground data sharing. The project was focused on supporting validation exercises for validation seamless operation among different centres performing coordination and transfer functions, as well as Point and Skip functionality based on the flight object interoperability,. The project also worked to support the Interoperability (IOP) allowing the sharing a whole common Flight Object (i.e. far richer information) instead of a specific subset of current flight plan information defined in several On-Line Data Interchange (OLDI) messages as well as supporting the Validation of the impact on the Air Traffic Controller activities due to the complete and continuous Flight Object synchronisation. Finally the project also supported the availability of Initial 4D data and an improved mechanism to distribute information via the Flight Object (FO) provides an opportunity to feed Arrival Management systems with up-to-date flight information and to use the capabilities of Required Time of Arrival (RTA) equipped aircraft to fly very accurately to metering fixes in order to sequence the arrival flow. For the specific i4D Data Link technology aspects (i.e. ADS-C and Control Pilot Data Link Communications compliant to Aeronautical Telecommunication Network (version B2) this project relied completely on the deliverables as provided by project regarding to the Enhanced Data link Features for all phase of flight.

Appendix D Results of bottom-up research clustering

Results of the Engage bottom-up research clustering. See D3.9 [1] for details.

Cluster Nº	Cluster keywords
1	aop, airport, platform, validation, exercise, monitoring, requirement, performance, status, information, apoc, solution, task, definition, test, service, stakeholder, analysis, maturity, decision
2	solution, package, validation, service, operator, airport, maturity, airspace, route, information, performance, benefit, system, concept, tma, improvement, separation, environment, step, safety
3	requirement, status, block, title, message, system, service, information, route, category, controller, function, clearance, ground, trajectory, runway, identify, prototype, position, test
4	controller, atco, system, tower, sequence, airport, function, automation, requirement, runway, task, operator, information, traffic, safety, solution, workload, aerodrome, situation, aman
5	sector, airspace, trajectory, route, complexity, network, traffic, conflict, information, system, actor, service, demand, planning, solution, capacity, dcb, requirement, measurement, controller
6	passenger, airline, delay, cost, modelling, airport, capacity, network, mechanism, transport, ansps, value, price, sector, trajectory, indicator, number, scenario, travel, airspace
7	swim, service, supervision, prototype, validation, step, enablers, specification, information, system, interoperability, standardisation, requirement, standard, exchange, description, definition, infrastructure, technology, maturity
8	assessment, material, security, modelling, solution, risk, application, stakeholder, guidance, recommendation, task, mfa, change, technique, validation, system, coordinator, package, information, deployment
9	gnss, navigation, surveillance, system, satellite, ground, gbas, gps, receiver, spectrum, frequency, signal, performance, solution, aeromacs, technology, cat, requirement, service, test
10	procedure, approach, rnp, pilot, operator, controller, demonstration, runway, airport, separation, validation, exercise, speed, system, navigation, concept, segment, fuel, scenario, noise
11	drone, service, operator, system, airspace, mission, information, risk, area, pilot, uas, scenario, capability, technology, navigation, security, traffic, rule, aviation, zone
12	uncertainty, modelling, trajectory, system, predictability, approach, information, sector, weather, controller, scenario, simulator, value, network, conflict, traffic, parameter, method, analysis, forecast
13	rpas, pilot, rpa, exercise, controller, procedure, demonstration, atco, simulator, traffic, mission, operator, loss, contingency, airspace, atc, safety, airport, emergency, intruder
14	trial, demonstration, exercise, fuel, route, airline, efficiency, traffic, procedure, reduction, benefit, delay, regulation, sector, arrival, pilot, impact, capacity, tta, period

EUROPEAN PARTNERSHIP

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Appendix E Dedicated catalyst fund reporting

Engage deliverables republishing each catalyst fund project's final technical report

Del. num.	Project title	Consortium (coordinator; partners)
D4.1	Probabilistic weather avoidance routes for medium-term storm avoidance ('PSA-Met')	Universidad de Sevilla; MeteoSolutions GmbH
D4.2	airport-sCAle seveRe weather nowcastinG project ('CARGO')	Università degli Studi di Padova; LMU Munich; GReD srl; Leonardo GmbH
D4.3	Authentication and integrity for ADS-B	TU Kaiserslautern; SeRo Systems GmbH
D4.4	Data-driven trajectory imitation with reinforcement learning	University of Piraeus Research Center; Boeing Research and Technology Europe
D4.5	A Data-drIven approach for dynamic and Adaptive trajectory PredictiON ('DIAPasON')	CRIDA; Deep Blue; ZenaByte
D4.6	Operational alert Products for ATM via SWIM ('OPAS')	Royal Belgian Institute for Space Aeronomy
D4.7	An interaction metric for an efficient traffic demand management: requirements for the design of data-driven protection mechanisms ('INTERFACING')	Aslogic 2011 S.L.
D4.8	MET enhanced ATFCM	France Aviation Civile Services; MetSafe
D4.9	Exploring future UDPP concepts through computational behavioural economics	Nommon Solutions and Technologies
D4.10	The drone identity - investigating forensic-readiness of U-Space services	Open University; NATS
D4.11	Proof-of-concept: practical, flexible, affordable pentesting platform for ATM/avionics cybersecurity ('ATM-cybersec')	University of Jyväskylä
D4.12	Safe drone flight - assuring telemetry data integrity in U-Space scenarios ('SDF')	NATS; Open University
D4.13	Flight centric ATC with airstreams ('FC2A')	NEOMETSYS; ENAC
D4.14	Meteo Sensors In the Sky ('METSIS')	NLR; AirHub B.V.
D4.15	Probabilistic information Integration in Uncertain data processing for Trajectory Prediction ('PIU4TP')	CIRA
D4.16	Collaborative cyber security management framework	Winsland Ltd; Movable-type; MSDK; BULATSA
D4.17	Role of Markets in AAS Deployment ('RoMiAD')	Think Research Ltd
D4.18	Weather impact prediction for ATFCM ('WIPA')	France Aviation Civile Services; MetSafe

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