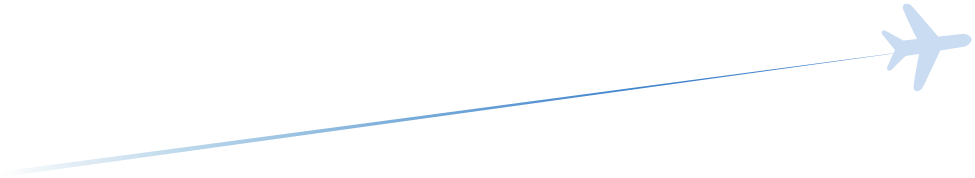

D2.6 Annual combined thematic workshops progress report (series 2)

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Authoring & Approval

Authors of the document

Name/Beneficiary	Position/Title	Date
Tatjana Bolić / University of Westminster	Consortium member	08 February 2021
Andrew Cook / University of Westminster	Project coordinator	08 February 2021
Pablo Hernández / Innaxis	Consortium member	08 February 2021
Paula López / Innaxis	Consortium member	08 February 2021
Dirk Schaefer / EUROCONTROL	Consortium member	08 February 2021
Luis Delgado / University of Westminster	Consortium member	08 February 2021

Reviewers internal to the project

Name/Beneficiary	Position/Title	Date
Graham Tanner / University of Westminster	Consortium member	25February 2021

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	26 February 2021

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

The preparation, organisation and conclusions from the thematic challenge workshops, two *ad hoc* technical workshops, a technical session on data and a MET/ENV workshop held in 2019 and 2020 are described. Partly due to Covid-19, two of the 2020 thematic challenge workshops scheduled to take place at the end of 2020 were re-scheduled to January 2021. We also report on the preparation for these two workshops, while the conclusions will be included in the next corresponding deliverable.

Acknowledgement. The authors would like to acknowledge valuable inputs from the workshop participants, and especially to Nommon Solutions and Technologies (Spain) for collaboration on materials and texts relating to Thematic Challenge 4, and for the content of Annex B.

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Executive Summary

The purpose of this document is to report on the activities directly and indirectly linked with the thematic challenge workshops:

- Thematic challenge (TC) workshops and the review of the topics;
- Engage catalyst fund projects and PhD support;
- Technical workshops.

Table 1 lists the TC workshops held in 2019 and 2020, and the two workshops re-scheduled from the end of 2020 to the beginning of 2021.

Table 1. List of workshops held in 2019 and 2020, and those currently planned for 2021.

Thematic challenge	Workshop series (edition)	Date and place held/planned
TC1	1	27 March 2019, Brussels, Belgium
TC3	2	05 November 2019, Brussels, Belgium
TC4	2	12 November 2019, Madrid, Spain
TC2	2	02 December 2019, Athens, Greece
TC4	*N/A*	27 July 2020, virtual event*^
TC1	2	10 November 2020, virtual event
TC2	3	25 January 2021, virtual event
TC3	3	27 January 2021, virtual event
TC4	3	May 2021 (TBC) ^

TC1 - Vulnerabilities and global security of the CNS/ATM system
TC2 - Data-driven trajectory prediction
TC3 - Efficient provision and use of meteorological information in ATM
TC4 - Novel and more effective allocation markets in ATM
* Included here to exemplify the independent catalyst fund workshops and the continuity of TC4 activity
^ See also Section 4.1.4 and Annex B

In addition to the TC workshops, Engage organised two technical workshops aimed at introducing the data sources and techniques used to build passenger itineraries to interested Engage PhD students. Further, during the Engage summer school, EUROCONTROL presented the new data repository, the R&D data archive. Thanks to the links with TC3, Engage also participated in the organisation of SJU's workshop with ER4 MET/ENV projects.

Table 2. List of technical workshops.

Technical workshops	Workshop series (edition)	Date and place held
Building passenger itineraries	1	10 March 2020, Madrid, Spain
Building passenger itineraries	2	13 July 2020, virtual event
Technical session on access to EUROCONTROL data sources for catalyst funding and PhDs	1	23 September 2020, virtual event part of Engage KTN's 2nd summer school
SJU's ER&IR MET and ENV workshop*	1	01 October 2020,virtual event

*The workshop was organised by the SJU, Engage's coordinated with catalyst funding projects and PhD students.

All the workshops generated interest and highlighted new research directions. Over the past two years of workshop organisation, the lessons learned list expanded to include the following:

1. The four chosen TCs will continue to be fostered until the end of the project, as there is not enough time to properly call for new topics and organise the teams to support them.

2. TC2 and TC3 reached further maturity, with a focus on creating research inputs for the next SESAR partnership. For example, TC3 strives to channel the collaboration of catalyst funding projects, and ER4 and IR projects to inform and shape the needs and performance input for the Green Aviation roadmap of the European Partnership for integrated ATM.

3. As the Engage KTN is coming to an end in 2021, it is important to capture the achievements of the thematic challenges, the associated catalyst fund projects (which will be closed by mid 2021) also drawing on the PhD progress thus far, where appropriate, in particular identifying opportunities for future research, plus barriers and enablers regarding transfer to higher TRLs. This summary should be made after the next round of TC workshops (see Section 5.3).

4. The workshops we are reporting in this deliverable were all (bar one) held in the face-to-face environment, during one working day, which was appreciated by participants. Due to the Covid-19 restrictions, the last TC1 workshop was held virtually and lasted half a day. The next TC2 and TC3 workshops will be held in January 2021 and have a full day schedule. It is to be seen which of the two settings (half day or a full day) is more convenient in the virtual setting, also taking into account the goals of the workshops and the density of virtual events in this period.

5. There is a need for different data sets and data processing algorithms if ATM research in Europe is to progress. Some of the data sets can be obtained relatively easily, such as the trajectory data available through EUROCONTROL's R&D archive (similar to DDR2 data), or ADS-B trajectories from the OpenSky network. For other data sets, such as schedules, passenger itineraries or fares, the projects need to set aside considerable budget to be able to acquire them. Meteorological data in Europe is fragmented. Obtaining the data is just a first step in any research as even the cleanest data has to be prepared for the purpose of the specific research project. There are some techniques/algorithms that various research institutions developed over the years. ATM research might well benefit from an exchange of experiences in this area, which the technical workshops with the Engage KTN students demonstrated. The Engage wiki data repository could provide a useful environment for such data (and code) sharing, especially for common (clean) data sets to promote cross-project comparison and calibration/validation (which is currently lacking).

6. The last TC1 workshop (10NOV2020) added a post-event survey. The response rate was quite high and good feedback was received. It is something the next workshops will take into account as a post-event survey can help in the following:
    - Obtaining individual participants' input on the workshop conclusions, helping to elaborate workshop conclusions.
    - Receiving feedback on the quality of the agenda and the balance between the operational and research issues presented and discussed.

1 Introduction

1.1 Objectives of this document

This document reports on the organisation and results obtained from the thematic challenge and technical workshops in 2019 and 2020. The deliverable due date was the end of 2019, but it was delayed to allow for the thematic challenge (TC) 1 workshop results to be included. The initial plan for the TC1 was to be held at the beginning of 2020 (a year after the corresponding, previous workshop), which was affected by the pandemic situation. After postponing the original date for an on-site event in summer 2020, the workshop was moved to an online format later in the year.

1.2 Scope

The scope of the deliverable is to report on the activities directly and indirectly linked with the thematic challenge workshops:

- Thematic challenge (TC) workshops and the review of the topics;
- Engage catalyst fund projects and PhD support;
- Technical workshops.

Section 2 describes the preparation and execution of TC and technical workshops; Section 3 gives the description of the TC challenge and summary of the TC workshop conclusions, together with the conclusions from the technical workshops. Section 4 gives an overview of lessons learned in this period, lessons learned related to the content of the challenges and the organisation of workshops. Section 5 lists the next steps, while the TC1 survey material can be found in Annex A.

1.2.1 Thematic challenge review

The goal of thematic challenges was to address research topics not currently (sufficiently) addressed by SESAR, by providing initial description of the topics that were expanded through the interaction with interested stakeholders in the dedicated workshops. The call for thematic challenges was open on the Engage website between January and March 2018. The selection process resulted in (described in detail in the deliverable D3.4) four thematic challenges to pursue in the first year of the KTN:

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 the material from the workshops, like presentations, descriptions of challenges and workshop conclusions is public and is published on the Engage website.

At the intermediate progress meeting it was decided to reassess the thematic challenges after the results of the Exploratory Research (ER) call 4 and Catalyst funding (CF) wave 2 are known. At the time of the writing of this deliverable, the results of the two calls were known. The Engage KTN decided to keep the TCs as they are, as the process to call for different topics is lengthy and would leave no time for proper organisation of workshops or the possibility to exploit the results.

1.2.2 Catalyst funding and PhD links

As one of the strong points of the Engage KTN is its focus on selecting thematic challenges that require further research efforts, but also offering paths to address them:

- Engage catalyst funding:
    - In wave 1 the Engage KTN funded 10 projects, most of which are completed (due to the Covid-19 related delays five projects obtained extensions of varying lengths).
    - In wave2 the Engage KTN is funding further eight projects, that started over the summer of 2020.
- Engage PhDs/theses - the Engage KTN is currently funding 10 PhD students.

The aim of the catalyst funding is to further promote cooperation between industry and academia, between ER and applied research, by funding focused projects, stimulating the transfer of exploratory research results towards ATM application-oriented research. This funding has been awarded to groups (e.g. an industry partner leading a thematic challenge, and two academic institutions 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 the conclusions to be included in the material for the catalyst funding calls. We are now at the third round of the TC workshops, and the goal now is to present the results from the wave 1 catalyst funding (CF) projects and introduce the wave 2 projects.

1.2.3 Technical workshops

As the Engage KTN progresses, its activities (i.e. TC workshops, CF projects, PhD theses) are producing results. As already mentioned in Section 1.2 the TCs are to be reassessed as they seem to have created impact. On the other side, the Engage KTN has received requests for highly specialised topics, mostly from the PhD students. As such in 2020 the Engage KTN organised two workshops addressing the data and the steps needed to build passenger itineraries.

2 Preparation and execution of workshops

Five TC workshops (see Table 3) and three technical workshops (see Table 5) were held to-date. The "Vulnerabilities and global security of the CNS/ATM system" workshop was postponed to March 2019, as it was not possible to organise the workshop before the publication of catalyst funding call and SESAR Innovation Days. This is described in more detail below, in Section 2.1.2.

Two workshops, TC2 and TC3 were supposed to be held at the end of 2020. Due to the proliferation of virtual events at the end of the year, and partly due to the pandemic, these two workshops were delayed to January 2021. Here, we report on the workshop preparations.

2.1 Thematic challenge workshops

Here we report on preparation and execution of the TC and technical workshops and sessions in 2019 and 2020. Table 1 below lists the TC workshops held in the previous period, and the two workshops planned at the beginning of 2021.

Table 3. List of TC workshops held in 2019 and 2020, and those planned for January 2021.

Thematic challenge	Workshop series (edition)	Date and place held/planned
TC1 - Vulnerabilities and global security of the CNS/ATM system	1	27 March 2019, Brussels, Belgium
TC3 - Efficient provision and use of meteorological information in ATM	2	05 November 2019, Brussels, Belgium
TC2 - Data-driven trajectory prediction	2	02 December 2019, Athens, Greece
TC1 - Vulnerabilities and global security of the CNS/ATM system	2	10 November 2020, virtual event
TC2 - Data-driven trajectory prediction	*3*	*25 January 2021, virtual event*
TC3 - Efficient provision and use of meteorological information in ATM	*3*	*27 January 2021, virtual event*

The format of the TC workshops was originally chosen in the first round of workshops, as reported in the D2.5 Annual combined thematic workshops progress report (priming wave 1). The format consisted in the following: one day workshop, free of charge to attend, and expected to be relatively small (around 30 participants). Small workshops allow to have a strong emphasis on discussion regarding the maturing of the challenge, with facilitated discussion. The goal of the presentations on the agenda was to inspire the discussions. Interdisciplinarity is strongly encouraged, with limited funds to pay for such speakers' travel. As reported in D2.5, this format met the approval of participants. Furthermore, it was conducive to reaching specific goals of each workshop.

Each TC was supported by a dedicated team, composed of Engage partners, proposers, and SJU members collaborated in the preparation of workshops, addressing the following:

1. Workshop planning:
    - choice of venue and date,
    - choice of the workshop agenda (number and length of presentations, number and length of discussions),
    - choice of speakers,
    - choice of moderators for discussion sessions,
    - identification of the list of people / organisations / projects that should be involved in the workshop (NOTE: the participation at the workshops is open to all interested parties, not only to the people/organisations/projects identified here.)
2. Streamlining the collection of workshop results and conclusions. The goal being to develop a common (across all challenges) method of presenting the results and identifying set of measures (metrics) for quantifying success.

Each TC team developed the abstracts, programmes, and conclusions which were published on the Engage website.

Table 4. Engage partners supporting TCs.

TC	Engage partners supporting (no implied order)
1	Innaxis, EUROCONTROL, Frequentis
2	University of Belgrade, EUROCONTROL
3	University of Trieste, Technical University of Delft
4	University of Westminster, University of Trieste

As already mentioned, the participation was open to all interested parties. However, as the venues had a physical limit on the number of participants (usually between 30-40 participants), and to be able to communicate the workshop details to the participants, the consortium setup the registration process. To request a place, participants should visit: engagektn.com/thematic-challenges. Each workshop has a dedicated registration form, that collects participants' names, email addresses and organisations. The workshops were publicised through the Engage website, SESAR JU e-news, LinkedIn and Twitter, as well as through the direct invitation of the participants of the past workshop editions.

The sections below contain the abstract, and the workshop programme for all four TCs. The longer descriptions of the thematic challenges and the conclusions from the three held workshops are given in the next section.

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

2.1.1.1 First workshop (TC1.1), 27 March 2019, Brussels, Belgium

The initial planning was to hold the workshop on 31st October 2018, but many of the invited experts could not participate due to the bank holiday on November 1st. The second proposed date was November 15th, but that was also not doable as most experts were already committed to other events (one being High Level group meeting on cybersecurity for aviation, organized by EASA on the same date). As it was not possible to hold the workshop before the publication of catalyst funding call and SESAR Innovation Days, the TC team decided to postpone it until the call is closed, thus moving the workshop to March of 2019.

2.1.1.1.1 TC1.1 Abstract

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.

2.1.1.1.2 TC1.1 Workshop Programme

Figure 1 shows the programme of the first TC1 workshop.

Figure 1. TC1.1 workshop programme.

2.1.1.1.3 TC1.1 Attendance

The capacity of the venue was 38 people, 35 participants attended the workshop.

2.1.1.2 Second workshop (TC1.2), 10 November 2020, virtual event

Initially, the workshop was planned to be held at Frequentis offices in Vienna, in April or May of 2020. However, due to Covid-19, it was first postponed to the 17th of June. As the situation was not improving, it was postponed to November 2020, still hoping for the face-to-face workshop. Finally, the consortium took a decision to go for a virtual event, on 10 November 2020.

2.1.1.2.1 TC1.2 Abstract

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.

2.1.1.2.2 TC1.2 Workshop programme

Figure 2 shows the programme of the second TC1 workshop.

Figure 2. Second TC1 workshop programme.

2.1.1.3 TC1.2 Attendance

Registration collected 66 expressions of interest to participate. Finally, there were 36 active participants between speakers, Engage team and delegates.

2.1.2 TC2 - Data-driven trajectory prediction

2.1.2.1 Second TC2 (TC2.2) workshop

Workshop date: **02 December 2019**

Host: National Centre of Scientific Research 'Demokritos'

Address: Athens, Greece (co-located with SIDs)

Web details for access: https://www.sesarju.eu/sesarinnovationdays

2.1.2.1.1 TC2.2 - Abstract

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

2.1.2.1.2 TC2.2 - Workshop programme

Programme

0930-1000 Welcome coffee

1000-1015 ***Welcome and overview from the Engage KTN; results of the 2018 workshop***

Dirk Schaefer (EUROCONTROL) and Andrew Cook (University of Westminster)

SESSION 1 (1015-1145): Engage catalyst-funded projects (chair Dirk Schaefer)

1015-1045 ***Data-driven trajectory imitation with reinforcement learning***

Theocharis Kravaris (University of Piraeus)

1045-1115 ***A Data-drIven approach for dynamic and Adaptive trajectory PredictiON ('DIAPasON')***

Manuel Cordero (CRIDA)

1115-1145 ***An interaction metric for an efficient traffic demand management: requirements for the design of data-driven protection mechanisms***

Juan José Ramos (Aslogic)

1145-1215 ***Discussion on problems and opportunities***

1215-1315 ***Lunch***

SESSION 2 (1315-1500): Engage PhDs (chair Luis Delgado)

1315-1335 ***Trajectory planning for conflict-free trajectories: a multi agent reinforcement learning approach ('RL4CFTP')***

Alevizos Bastas (University of Piraeus)

1335-1355 ***Machine Learning Techniques for Seamless Traffic Demand Prediction***

Manuel Mateos (Nommon)

1355-1415 ***Machine Learning Applications to Extend AGENT's conflict resolution capabilities***

Ralvi Isufaj (Autonomous University of Barcelona)

1415-1435 ***Advanced Statistical Signal Processing for Next Generation Trajectory Prediction***

Homeyra Khaledian (Technical University of Catalonia)

1435-1455 ***Integrating weather prediction models into ATM planning ('IWA')***

Anastasia Lemetti (Linköping University)

1455-1515 ***Discussion on problems and opportunities***

1515-1530 ***Coffee break***

SESSION 3 (1530-1630): Facilitated brainstorming

1530-1615 ***Identification of areas of collaboration and opportunities***

1615-1630 ***Wrap-up and close-out***

Dirk Schaefer (EUROCONTROL) and Andrew Cook (University of Westminster)

2.1.2.1.3 TC2 Attendance

The workshop was held at the beginning of the SESAR Innovation Days in Athens, and we had 39 registrations, with 37 participants attending the workshop.

2.1.2.2 Third TC2 (TC2.3) workshop

Scheduled for 25th January 2021, virtual event.

2.1.2.2.1 TC2.3 Agenda

Programme

1000-1015 **Welcome and overview from the Engage KTN; overview of TC2 and previous workshops -** *Dirk Schaefer (EUROCONTROL), Tatjana Bolic (University of Westminster) and Andrew Cook (University of Westminster)*

SESSION 1 (1015-1155, chair: Dirk Schaefer)

1015-1040 **Uncertainty modelling and data assimilation to propagate aircraft trajectory uncertainties using polynomial chaos expansions -** *Andrés Muñoz (Boeing) and Manuel Soler (University Carlos III Madrid)*

1040-1105 **Prediction of propagation and evolution of delays with machine learning -** *Ramon Dalmau Codina (EUROCONTROL)*

1105-1130 **Trajectory Prediction via Imitation Learning -** *George Vouros (University of Piraeus)*

1130-1155 **Clustering & Complexity measures of European traffic -** *Didier Dohy (NeoMetSys)*

1155-1300 ***Lunch***

SESSION 2 (1300-1530, chair: Tatjana Bolic)

1300-1330 **A Data-drIven approach for dynamic and Adaptive trajectory PredictiON ('DIAPasON') -** *Jose Manuel Cordero (CRIDA)*

1330-1400 **Probabilistic information Integration in Uncertain data processing for Trajectory Prediction -** *Francesco Martone, CIRA*

1400-1430 **An interaction metric for an efficient traffic demand management: requirements for the design of data-driven protection mechanisms -** *Juan José Ramos (Aslogic)*

1430-1500 ***Coffee break***

1500-1530 **OpenSky: Crowdsourcing Data Collection for ATM Research -** *Martin Strohmeier, University of Oxford*

SESSION 3 Engage PhDs (1530-1645, chair Andrew Cook)

1530-1600 **PhD presentations**

- ***Machine Learning Applications to Extend AGENT's conflict resolution capabilities -*** *Ralvi Isufaj (Autonomous University of Barcelona)*
- **Advanced statistical signal processing for next generation trajectory prediction -** *Homeyra Khaledian (Technical University of Catalonia)*
- **Data-based Pre-tactical Trajectory Prediction -** *Manuel Mateos (Nommon)*

1600-1630 **Discussion**

1630-1645 **Wrap-up and close-out -** *Dirk Schaefer (EUROCONTROL) and Andrew Cook (University of Westminster)*

2.1.2.2.2 TC2.3 Registration

At the time of the writing, there were 27 registered participants.

2.1.3 TC3 - Efficient provision and use of meteorological information in ATM

2.1.3.1 Second TC3 (TC3.2) workshop

Workshop date: **05 November 2019**

Host: SESAR Joint Undertaking

Address: Avenue de Cortenbergh 100, 1000 Brussels, Belgium

Web details for access: https://sesarju.eu/about-us/visiting-us

2.1.3.1.1 TC3.2 Abstract

In this workshop we take forward the discussions of our first event, held at the SESAR JU premises in November 2018, and introduce the research now being supported by the SESAR KTN, Engage, through its newly-launched PhDs and catalyst fund projects. Our presentations start with the PhD presentations, offering time for discussions on problems and opportunities in this research, as well as remaining gaps. We then turn to the NM perspective and environmental advances, to pave the way for the description of newly funded catalyst projects. We conclude with a facilitated workshop, a key output of which will be how to integrate these early activities in the wider ATM innovation, and what the next steps ought to be.

2.1.3.1.2 TC3.2 Workshop programme

Programme

(May be subject to further small changes)

0900-0930 Registration

SESSION 1 Introduction

0930-0945 ***Welcome and introduction to the programme***

Welcome by our hosts, SJU and the introduction to the SESAR KTN, Engage, and the day's programme

Dr Tatjana Bolic (University of Trieste), Luca Crecco (SESAR JU)

SESSION 2 MET and the Engage PhDs

0945-1015 ***A pilot/dispatcher support tool based on the enhanced provision of thunderstorm forecasts considering its inherent uncertainty ('STORMY')***

Prof Manuel Soler (UC3M)

1015-1045 ***Weather Impact on Flight Efficiency for Stockholm Arlanda Airport Arrivals***

Anastasia Lemetti (Linköping University)

1045-1100 ***EASA's Weather Information to Pilots Strategy Paper***

Christopher Tyson (EASA)

1100-1115 ***Discussion - problems and opportunities***

1115-1130 ***Coffee break***

1130-1200 ***MET advances in the NM***

Rosalind Lapsley (EUROCONTROL)

1200-1230 ***Aviation environmental impact assessment***

Dr Sigrun Matthes (DLR)

1230-1330 ***Lunch***

SESSION 3 The Engage catalyst funded projects & industry perspectives

1330-1350 ***airport-sCAle seveRe weather nowcastinG project ('CARGO')***

Dr Riccardo Biondi (University of Padova)

1350-1410 ***Operational alert Products for ATM via SWIM ('OPAS')***

Dr Hugues Brenot (BIRA)

1410-1430 ***Probabilistic weather avoidance routes for medium-term storm avoidance ('PSA-Met')***

Prof Damian Rivas (University of Seville)

1430-1450 ***MET enhances ATFCM***

Kamel Rebaï (METSAFE) and Maxime Warnier (METSAFE)

1450-1510 ***Coffee break***

SESSION 4 Facilitated workshop

1510-1515 ***Introduction to the facilitated workshop***

Tatjana Bolic

1515-1615 ***Facilitated workshop***

- Problems and opportunities coming from catalyst funded projects.

- Further areas to address – en-route and airport.

1615-1645 ***Wrap-up, conclusions, wider next steps***

Tatjana Bolic, Luca Crecco

2.1.3.1.3 TC3.2 Attendance

We had the limit of 30 places, and received 20 registrations, with 17 people being present at the workshop.

2.1.3.2 Third TC3 (TC3.3) workshop

Scheduled for 27th January 2021, virtual event.

2.1.3.2.1 TC3.3 Abstract

The overall goal of this edition is to streamline the innovation pipeline in the area of efficient provision and use of meteorological/environmental information in the ATM. We start by presenting research results supported by the SESAR's KTN, Engage, through the catalyst funded projects and PhDs, aiming at discussion on finding the ways of bringing the valuable results to the higher TRL levels and foster the collaboration in this research area. The next step is the overview of the newly funded projects in the MET/ENV area, the progress in the European forecast provision, and finally the plans for MET/ENV research in the Strategic Research and Innovation Agenda of future Integrated ATM programme. The overall goal is to discuss and list the kind of information of tools would the climate change and the digitalisation of ATM require from MET/ENV-related research.

2.1.3.2.2 TC3.3 Programme

Draft programme

0930-0945 Welcome by SESAR Joint Undertaking and Engage KTN

Welcome by our hosts, SJU and the introduction to the SESAR KTN, Engage, and the day's programme

Dr Tatjana Bolic (University of Westminster), Luca Crecco (SESAR JU)

SESSION 1 Catalyst Funding Wave 1 results

0945-1015 ***Probabilistic weather avoidance routes for medium-term storm avoidance ('PSA-Met')***

Dr Antonio Franco Espin, (University of Seville)

1015-1045 ***airport-sCAle seveRe weather nowcastinG project ('CARGO')***

Dr Riccardo Biondi (University of Padova)

1045-1115 ***Operational alert Products for ATM via SWIM ('OPAS')***

Dr Hugues Brenot (BIRRA)

1115-1130 ***Coffee break***

SESSION 2 **Catalyst Funding Wave 2 and the Engage PhDs**

1130-1210 ***MET enhanced ATFCM and WIPA***

Gladys Mercan and Kamel REBAÏ (METSAFE)

1210-1230 **Metsis**

Dr Emmanuel Sunil

1230-1245 **Engage PhDs**

"Integrating weather prediction models into ATM planning", Anastasia Lemetti (Linköping University)

"A pilot/dispatcher support tool based on the enhanced provision of thunderstorm forecasts considering its inherent uncertainty ('STORMY')", Eduardo Andrés (UC3M)

1245-1300 **ALARM project**

Prof Manuel Soler (UC3M)

1300-1400 ***Lunch***

SESSION 3 **New developments for MET/ENV in ATM**

1400-1415 **Integration of dynamic weather cells in collaborative ATFCM - ISOBAR project**

Marta Sánchez Cidoncha (CRIDA)

1415-1445 ***Discussion - Catalyst Funding results and how they can be further exploited***

Moderator: Dr Tatjana Bolic (University of Westminster)

1445-1500 **Overview, *synergies and possibilities for collaboration between new MET/ENV projects***

Luca Crecco (SJU)

1500-1520 ***European weather forecast provision***

Rosalind Lapsley (EUROCONTROL)

1520-1535 ***New SRIA and MET/ENV***

Philippe Lenne (SJU)

1535-1615 ***Discussion - information and tools from MET/ENV related research needed to address the climate change and the digitalisation of ATM***

Moderator: Luca Crecco (SJU)

- Problems and opportunities in climate change and ATM digitalisation.

- MET/ENV performance assessment needs

1615-1630 ***Wrap-up, conclusions, wider next steps***

Tatjana Bolic, Luca Crecco

2.1.3.2.3 TC3.3 Registration

At the time of the writing there are 45 registered participants.

2.1.4 TC4 - Novel and more effective allocation markets in ATM

Workshop date: **12 November 2019**

Host: Nommon

Address: Hotel VP Madroño, General Díaz Porlier 101

28006 Madrid, Spain

Web details for access: https://www.madrono-hotel.com/en/

2.1.4.1 TC4 - Abstract

In this workshop we take forward the discussions of our first event, held in London in October 2018, and introduce the research now being supported by the SESAR KTN, Engage, through its newly-launched PhDs and catalyst fund project. Our presentations start with expert viewpoints from outside the ATM domain, then focus more on the application of behavioural economics within ATM, before concluding with a facilitated workshop, a key output of which will be how we integrate these early activities in this new field, and what the next steps ought to be.

2.1.4.2 TC4 - Workshop programme

Programme

0830-0900 Registration

SESSION 1 Introduction

0900-0930 ***Welcome and introduction to the programme***

An introduction to our hosts, Nommon, to the SESAR KTN, Engage, and the day's programme

Ricardo Herranz (Nommon), Andrew Cook (University of Westminster)

0930-1000 ***A view from the outside looking in***

The background to behavioural economics and some applications beyond ATM

Benno Guenther (Salient)

1000-1030 ***The challenge of allocating scarce resources***

A comparison of methods for allocating scarce resources in air transport

Lorenzo Castelli (University of Trieste)

1030-1050 ***Coffee break***

1050-1120 ***Behavioural economics – finding a place in ATM***

How this new field is being taken up in ATM, and where it might take us next

Andrew Cook

SESSION 2 Behavioural economics and the Engage PhDs

1120-1150 ***Investigation into 'irrational' airline strategies***

Exploring ground operations as crucial control elements in airline networks

Hartmut Fricke (TU Dresden)

1150-1220 ***The bridge between optimisation and simulation: application to APOC***

The benefit of coupling optimisation and simulation in order to enhance decisions in a multi-agent environment

Daniel Delahaye (ENAC)

1220-1330 ***Lunch***

SESSION 3 The Engage catalyst fund & industry perspectives

1330-1400 ***What UDPP hopes to deliver to the airspace users***

The importance of designing the right mechanism and understanding the drivers of the user

Nadine Pilon (EUROCONTROL)

1400-1430 ***Exploring future UDPP concepts through computational behavioural economics***

Insights into the Nommon Engage catalyst fund project, with a focus on flight prioritisation

David Mocholí (Nommon)

1430-1500 ***Coffee break***

SESSION 4 Facilitated workshop

1500-1515 ***Introduction to the facilitated workshop***

Andrew Cook

1515-1715 ***Facilitated workshop***

Delegates will be presented with novel flight prioritisation mechanisms, and discuss the pros and cons from various stakeholder perspectives, in break-out groups. What are the most important metrics (flexibility, cost-efficiency, resilience, equity?) and how should we measure them?

In plenary, a round-table discussion will follow on: the extent to which the stakeholder metrics can be reconciled; what contribution behavioural economics can make to mechanism design and performance; plus conclusions and next steps for such research.

1715-1730 ***Wrap-up, conclusions, wider next steps***

How we integrate these early behavioural economics research elements and what the wider next steps ought to be for industry in general and the integrated Engage perspective, in particular

Ricardo Herranz, Andrew Cook

2.1.4.3 TC4 Attendance

There were 21 registrations for the workshop, ending with 19 participants on the day of the workshop.

2.2 Technical workshops

In this section we summarise organisation of the technical workshops, those directly organised by the Engage KTN (i.e. Building passenger itineraries 1, 2, and EUROCONTROL's data sources) and those with the participation of Engage KTN.

Table 5. List of technical workshops organised or participated in by Engage KTN.

Technical workshops	Workshop number	Date and place held
Building passenger itineraries	1	10 March 2020, Madrid, Spain
Building passenger itineraries	2	13 July 2020, virtual event
Technical session on access to EUROCONTROL data sources for catalyst funding and PhDs	1	23 September 2020, virtual event part of Engage KTN's 2nd summer school
SJU's ER&IR MET and ENV workshop	1	01 October 2020, virtual event

2.2.1 Building passenger itineraries 1

Date: 10 March 2020

Location: Innaxis offices - Calle Genova, 11, 2D. Madrid - 28004

Objective: This technical workshop was aimed at Engage PhD students who will consider passenger related data in their research. The objective of the workshop was to present the datasets, challenges and techniques to produce realistic passenger itineraries (including connections). The workshop included technical activities and aimed at fostering the collaboration between PhD students using similar techniques and datasets.

Attendees: 4 Engage PhD students and 1 PhD supervisor. Out of 5 Engage PhD students who considered that this workshop would be beneficial, one was not able to attend due to the first impact of COVID.

2.2.1.1 Workshop programme

Instructors:

- Gerald Gurtner
- Luis Delgado

Table 6. Technical workshop 1 agenda.

Time	Topic category	Topic
9h30 - 9h40	Welcome / Introductions	
9h40 - 10h10	Why do we need pax data and definitions.	The relevance of passenger data in ATM research
10h10 - 10h40		Passenger data definitions
10h40 - 11h00		Need of pax data from PhD
11h00 - 11h10	Coffee break	
11h10 - 11h55	Datasets to be used to generate passengers' itineraries	Passenger datasets
11h55 - 12h10		Calibration datasets
12h10 - 12h20	Coffee break	
12h20 - 13h00	Challenges and techniques to build passenger itineraries	Approaches to generate pax itineraries
13h00 - 13h30		Technical discussion on approach for different modules
13h30 - 14h30	Lunch	
14h30 - 15h00	Previous experience examples	Examples of previous projects: ComplexityCosts and Vista
15h00 - 18h30	Technical work	
18h30	Finish	

2.2.2 Building passenger itineraries 2

Title: Follow up on passenger itineraries for decision-making tools and models workshop
Date: 13 July 2020 - 10h00-13h00 CEST

Location: virtual event

Attendees: 4 Engage PhD students

2.2.2.1 Workshop programme

Instructors:

- Gerald Gurtner
- Luis Delgado
- Andrew Cook
- Graham Tanner

Agenda:

1. Each participant to present
    a. Brief summary of PhD objective and need/use of passenger data
    b. Passenger requirements for PhD problem
2. Identify potential collaborations on passenger itineraries/scenarios (e.g., Sashiko, Jan and Jonas need a given airline itineraries at a hub)
3. Each participant to present
    a. Datasets used so far
    b. Modelling approach
    c. Needs (datasets, tools)
        i. What would you do if you get no further passenger data through Engage? What would be the consequences / severity for your PhD? When do you need the data / to take a decision, at the latest?
        ii. Are there particular issues with the data you currently have (e.g. inability to track aircraft rotations at turnaround) that might be resolved with support from Engage?
        iii. Are there other data you need (e.g. crew rosters)? Same question as (i) for these data.
4. We need to identify:
    a. Need of follow up meeting/workshop/activity as part of the summer school (remote 21-25 September 2020).
    b. Follow up collaborations between them
    c. Datasets we can provide/source

2.2.3 Technical session on access to EUROCONTROL data sources

Date: 23 September 2020, virtual event,

Location: part of Engage KTN's 2nd summer school

Instructor: David Marsh, EUROCONTROL

Link to the webinar: https://www.eurocontrol.int/event/quality-flight-data-research-and-development

The EUROCONTROL introduces the presentation recording as: “A rich source of accurate data can supercharge any research effort. To this end, at EUROCONTROL, we developed the Archive light data for R&D dashboard with over four years of accurate aviation data. To commemorate the dashboard's launch, we hosted an introductory session as part of the Engage network's second summer school. We introduced the dashboard to the summer school participants and showcased its many features. You can watch the recording below.”

2.2.3.1 Attendance

There were 80 registered participants for the summer school, and about 30-40 participants were present at different sessions, as not everyone was able to participate in every session.

2.2.4 Workshop with Exploratory and Industrial Research in MET/ENV area

Date: 01 October 2020

Location: Virtual event organised, and hosted by SJU, with the help of Engage's TC3.

2.2.4.1 Workshop programme and attendance

The goal of the workshop was to introduce the newly started projects in this scientific area to each other and discover the possibilities for collaboration and synergies. The workshop is intended as first step in trying to see if it will be possible, and in what manner, to cluster outputs of these projects in the MET/ENV solutions in the next TRL steps.

The speakers were the project coordinators, but the “silent” participation was extended to Engage KTN's catalyst funding projects and PhDs.

Agenda:

- Welcome (SJU) 09h30 - 09h40 (10')
- Solutions 29.2&29.3 (ECTRL) 09h40 - 10h10 (30')
- FlyATM4E (DLR) 10h10 - 10h40 (30')
- FMPMET (USE) 10h40 - 11h10 (30')
- Chat sessions (2 in parallel) 11h10 - 12h00 (50')
- Lunch break 12h00 - 13h00
- CREATE (UNIPARTH) 13h00 - 13h30 (30')
- DYNCAT (DLR) 13h30 - 14h00 (30')
- SINOPTICA (CIMA) 14h00 - 14h30 (30')
- Chat sessions (2 in parallel) 14h30 - 15h15 (45')
- Closing and way forward 15h15 - 16h00 (45')

There were about 15 participants. The workshop results will be presented at the TC3 workshop scheduled for 27th January 2021.

3 Workshop conclusions

All four thematic challenge themes held workshops in the period under report, TC1 two, while the other TCs held one workshop each. This is due to the TC1 delay in the first year, and as such the outcomes were not reported in the previous deliverable. The section contains description of the challenge for each TC, updated after each workshop, and the summary of the workshop conclusions.

These are also published on the Engage website, along with all the corresponding presentations (except where stated otherwise).

3.1 TC1.1 Description and workshop conclusions

3.1.1 TC1.1 Description of challenge

Data science applications are revolutionising many industries, including aviation. The increasing availability of data, coming from an increasingly sensorised and communicating sector, is multiplying the opportunities of delivering data and information-based solutions to diverse challenges, including fuel efficiency, safety, predictability and crew training. However, this is also opening new vulnerabilities or hazards that need to be faced, as declared by the Industry Consultation Body (2017) in its information paper, noting that the increasing reliance on inter-connected ATM systems, services and technologies increases the risk of cyberattacks.

From the human and organisational perspective, the growing potential impact of the described cyber threats require the cooperation and adaptation of mental models within the sector. Stakeholders involved in aviation and air transportation, and especially those directly interacting with the systems and basing their operations on them, need to be trained and prepared to understand and face the threats. Aviation stakeholders, airlines, airports, and air navigation service providers all operate different information management systems for their operational purposes. This generates a complex, multi-stakeholder, multi-system environment where the global security of the system architecture needs to be ensured and its cyber-resilience needs to be further reinforced through a combination of organisational, procedural and technological elements (Everdij *et al*., 2016). The reliability of the information displayed and used by ATM/CNS components is crucial to ensure the safe operation of a flight. Different ATM systems (e.g. ADS-B, datalink, SWIM, Asterix) are vulnerable to certain attacks (some of which might still be unknown), such as: corrupting, through false instructions or information, aeronautical communications broadcast in known frequencies (Strohmeier *et al*., 2015); ADS-B false-aircraft transmissions – so-called false data injection attacks (FDIA; e.g. see Cretin *et al*., 2018); and, attacking key infrastructure elements such as SWIM (system wide information management; e.g. see Everdij *et al*., 2016).

From the technological perspective, the complex, multi-stakeholder, multi-system environment that is developed for CNS/ATM, requires updates of software and firmware of IT components in order to resolve security vulnerabilities of any critical infrastructure. The problem of ensuring that vendors will indeed guarantee development and delivery of security upgrades and security patches for ten years or more will soon become of crucial importance. This is currently unsolved and involves several difficult issues: technical, economic and legal. These difficulties include either how to upgrade each

component, while ensuring capability with all other elements, or how to guarantee that this activity is economically sustainable over a long period. Taking into consideration the risks involved in the IT supply chain is an extremely challenging problem.

Considering the growing importance of communications, information and data sharing among ATM stakeholders, systems and components, it is necessary to ensure adequate protection against these and future potential attacks. Considering current global threats, it is pertinent to perform an initial security assessment of the elements supporting air navigation as well as their relationships, in order to identify its vulnerabilities. The collaboration of the different stakeholders plays a crucial role in achieving this objective, as highlighted by the ICB in its information paper (Industry Consultation Body, 2017), where sharing information about previous attacks and effective mitigations are considered a necessary step to protect the industry from future attacks. A European holistic, coherent, affordable and adaptable response that first understands the risks and then establishes mitigation measures is needed. The risk assessment should consider the potential impact of additional security measures to avoid unwanted effects regarding safety (e.g. TCAS encryption). On the other hand, it is necessary to apply controls to existing aviation and air traffic systems to detect exposure to attacks and make them cyber secure without having to replace and refit.

Certification, legal and liability issues should also be taken into account. Identifying the vulnerabilities and anticipating potential risks should then be used to design adequate mitigation actions and procedures that may imply certain changes in the system. Moreover, the legal frameworks necessary for providing concrete operational guidelines suitable for these novel forms of dependence are often still excessively vague. Assessing and managing these hazards is rapidly becoming an inescapable necessity in safety critical systems.

In a growing environment of data-driven applications (machine learning, artificial intelligence, data science, etc.) likely capable of further improving aviation performance, we need innovative data-sharing architectures capable of connecting and providing access to distributed data while preserving data privacy. The optimal data-sharing framework for a multi-stakeholder, multi-systems system like ATM, should be built on data owners' trust, placing data privacy at the heart of its architecture. The application of innovative, secure, distributed architectures, needs to be explored in the aviation domain as a potential path to ensure trust from both the technical and data usage/protocol perspectives. Further studies should also analyse the use of advanced, secure computing functions for privacy-preserving applications built over distributed applications.

As a particular example, to move to the managed service provision of surveillance data, such as space-based ADS-B, introduces the need for service suppliers to provide adequate assurance that the data are secure. Models applied have to ensure data integrity while considering security quality for data sources from multiple parties. A greater degree of technical integration and sharing data is also introduced with the intention of rationalising traditional radar information and the utilisation of layers of newer surveillance technologies to advance capabilities. This leads to the requirement of tight security of the information, further leading to the difficulty of how to constrain data accessibility with the potential reduction of precision that this action involves.

The information and communication technologies sector has made significant progress in this respect and, in particular, in the cybersecurity domain, which could be transferred to the aviation industry where several initiatives have also been launched. This previous work should serve as a basis for future research in the field. The SESAR cybersecurity strategy and framework study (SESAR, 2015), in particular, provides a European framework enabling the application of an aviation security maturity

model to define the roadmap towards fully secured aviation. Challenges covered therein are: bridging the gap between security risk management and the system-of-systems architecture (EATMA); strengthening cyber-resilience by linking with operational contingency; and, assessing different architectural options from a security perspective.

Focusing on the crucial security analysis and strategic protocols that are needed to mitigate the system's vulnerabilities, there is a necessity to analyse whether or not protocols contain weaknesses themselves or protocols scale to the new trust mechanisms required (i.e. do they contain the required security mechanisms, or have the ability to flexibly adopt new security mechanisms?). A deeper study of the security analysis of aviation-specific protocol implementations has to be carried out, especially for the case of a common software library used across vendors to implement a protocol specification, to know the security vulnerabilities content that these products could expose.

The considerations about data integrity and data sharing security is specifically important for the drones sector where operations rely on information exchange between the drone and its operator. In this case, the reliability of the connection and the security of the signal is closely related to the safety of the operations. This requires dedicated research and development to ensure the integrity of the drone telemetry and cyber-secure data transfer. Under this framework, specific regulatory actions for UTM are needed to ensure the required levels of cybersecurity for drone operations as well as to perform the accident and incident analysis, or investigations, when needed.

The CANSO *Cyber Security and Risk Assessment Guide* provides an overview of the threats and risks, including considerations for managing them and suggestions for a cybersecurity programme (CANSO, 2014). In addition, a number of workshops and research projects have been organised around this topic, helping to progress beyond the state of the art, foster the debate and promote the creation of an associated community. The following (non-exhaustive) list collects some of the most relevant activities.

- The EUROCONTROL ART workshop on cybersecurity (EUROCONTROL, 2016) focused on providing recommendations to foster progress in the field, covering regulatory, liability, validation, human and organisational aspects, including cooperation and harmonisation with other non-EU programmes.
- EASA and EUROCAE (2017) organised a workshop on technical standards to initiate the discussion about future rule-making and standardisation for cybersecurity in aviation.
- The GAMMA project (2017) developed a new vision, representing a concrete proposal for the day-to-day operation of air traffic management security. The ATM security solution proposed by GAMMA builds on the principles and concepts related to security management in a collaborative, multi-stakeholder environment, while maintaining a strong link with the current international and European legal frameworks, and the constraints imposed by national sovereignty issues.
- The European Strategic Coordination Platform (2017) on cybersecurity in aviation, organised by EASA, accepted a declaration which "called upon the European Commission and the European Aviation Safety Agency to develop and adopt Implementing Regulations addressing Cybersecurity in Aviation with harmonised common objectives but tailored requirements for subjects and sub-sectors, assuring commensurate responses to risks, called on airports, ground handling operators, maintenance organisations, air navigation service providers to develop information security management systems in accordance with specific procedures and appropriate standards, recommended to harmonise the security risk assessment methodologies, recognised that

cybersecurity is an interdisciplinary problem in transport that has its challenges in aviation, but also in shipping, rail and road transport, called upon a stronger partnership between regulators, operators, service providers, and manufacturing industry, in particular within the ESCP, where EASA welcomes and supports the Industry to come with standards."

- In 2018, DGAC France and EASA hosted the European Strategic Coordination Platform (ESCP) High Level Meeting. The purpose was to bring together States, industry, partners and other key players to raise awareness of cyber threats and attacks that could damage or disrupt critical infrastructures endangering airlines, airports and air traffic management. Potential actions, sustainable policies, approaches and measures to protect against them and mitigate their impact were also discussed and developed. See: DGAC and EASA (2018).
- In April 2019, IATA held, for the first time, an Aviation Cyber Security Roundtable (ACSR) in Singapore. This aimed to better understand and manage cybersecurity risks in civil aviation by sharing knowledge and experience, as well as developing tangible actions for the aviation industry. See: IATA (2019).
- In November 2019, the Israel Airports Authority (IAA) and EUROCONTROL conducted a joint cybersecurity exercise on aviation systems. The exercise consisted of various challenges in different fields related to cybersecurity. The objective was to help train cybersecurity experts of both organisations in order to maintain their skills in a fast-evolving domain. The IAA hopes to host similar annual events involving stakeholders from other EUROCONTROL Member States. See: Israel Airport Authority and EUROCONTROL (2019).
- 2019 also saw the launch of two Engage catalyst fund projects aligned with thematic challenge 1: "Authentication and integrity for ADS-B" (project coordinator: TU Kaiserslautern, Germany), and "The drone identity – investigating forensic-readiness of U-Space services" (project coordinator: The Open University, UK). (See Table 7 for the wave 2 catalyst fund projects.)

Making the most of the latest progress achieved in previous and on-going activities, this thematic challenge aims to pave the way towards a privacy-preserving, cyber-resilient, fault-tolerant and trustworthy system of systems, with all layers ensuring the integrity and availability of aeronautical data.

3.1.2 TC1.1 Workshop conclusions

Progress in security risk assessment is required (including the development of indicators for key risks) as a first step in understanding, controlling and preventing the vulnerabilities of the systems. In correctly addressing this need, the role of the operator needs to be considered as the end user of the system to be assessed and secured. Adequate training for operators should be provided in order to increase the awareness and develop operational procedures for risks identification and reaction.

To maintain safety levels, current ATM/CNS systems are subject to rigorous change-management procedures to ensure that required system updates do not have an adverse impact on the reliability of the system. However, if new security vulnerabilities are identified in an ATM/CNS system, there is pressure to update the system as quickly as possible to prevent it from being subject to attack. New approaches are required to develop systems that are capable of addressing these conflicting demands while maintaining resilience. As an example, the application of AI algorithms could be explored to proactively detect patterns and mitigate attacks.

Assuring the security of CNS/ATM systems requires shorter implementation times and updates/upgrades. Safety regulations are therefore challenged to face cybersecurity needs (e.g. patch management). The ability to rapidly patch vulnerabilities will be necessary when aircraft become more connected, which implies further development in certification processes of certified software (ED12-C). The requirements for certification of safety-critical systems should also include best practices from the security community.

While security information is usually protected as part of the security policies themselves, cooperation among security stakeholders is required in order to learn from previous security issues and attacks. The secure sharing of this information between ATM/CNS stakeholders is required at many levels. Examples include: post-incident forensics; real-time alerting of security incidents to connected partners; threats and vulnerabilities; lessons learned, for example detection, response and recovery methods.

New open models to enhance security should be developed in addition to the more traditional approach of security by obscurity. Aviation could learn from other sectors (e.g. banking) in order to overcome national sensitivities and confidentialities, to the benefit of a collaborative security culture.

When considering new security procedures and technologies, it is important to consider the social dimension. New developments in screening, monitoring, and tracking may potentially breach accepted norms for ethics, privacy, societal acceptance, and could be in breach of the regulatory framework. Consideration of such non-technical potential issues in advance of embarking on such programmes would be prudent. Engaging the whole society would help building cyber-resilient culture. Security governance framework needed to establish the common policies, legal aspects and procedures for all stakeholders to collaborate as a resilient ecosystem.

One of the main barriers that needs to be overcome for enabling data sharing is the confidentiality of the data sources. Nevertheless, the relative importance of confidentiality, integrity, and availability depends on the information in question and on the application area. There are particular data (e.g. ANSP staff personal data or state flights) where confidentiality and data anonymisation are essential. To address this challenge, there are research opportunities for applying encryption methodologies without compromising safety. However, for ephemeral operational data (e.g. radar tracks) integrity and availability are probably more important and their assessment needs to be further investigated.

Collaboration will be required beyond the aviation stakeholders. Future research projects will require cooperation between multiple transport modes and other sectors to obtain funding. Reducing environmental impact will be a key requirement, as well as the provision of evidence that core components are close to industrialisation. Contributing to the streamlining of safe and secure transport is also key.

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

1. Perform an initial security assessment of the elements supporting air navigation as well as their relationships, in order to identify its vulnerabilities and to ensure adequate protection against future potential attacks and current global threats;
2. Apply controls to existing aviation and air traffic systems to detect exposure to attacks and make them cyber secure without having to replace and refit. Certification, legal and liability issues should be taken into account;

3. Innovate data-sharing architectures capable of connecting and providing access to distributed data while preserving privacy, including the use of advanced, secure computing functions;
4. Confidentiality, availability and integrity requirements for aeronautical data need to be assessed per dataset and particular application;
5. Adapt mental models within the sector to prepare operators to understand and manage cyber threats;
6. Requirement of updating software and firmware of IT components in order to fix security vulnerabilities of any critical infrastructure;
7. Further research into the security analysis of aviation-specific protocol implementations (vulnerabilities, trust, software library) is required;
8. Explore open models to enhance security, complementing traditional approaches towards protection, potentially drawing on lessons learned and best practice from other sectors.

3.2 TC1.2 Description and workshop conclusions

The workshop conclusions presented here are the first draft as the TC team is still reviewing and fine tuning the final text. Thus, the text is still not published on the Engage website. See Section 5.3 for how this will be reported.

3.2.1 TC1.2 Workshop conclusions

By collecting and analysing the presentations held during the workshop, together with the following discussions, three clusters of topics or challenges were identified:

- information sharing infrastructure and performance monitoring;
- automation and AI/ML technologies in the aviation cybersecurity landscape;
- drones and UTM security.

More concrete challenges associated to cybersecurity in ATM were discussed during the presentations but most of them referred to one of these broader topics. The input collected during the workshop (both detailed and broad topics) was then distributed among the audience to measure their level of agreement/disagreement with the challenges identified by the speakers and to prioritize the most important areas.

Topic 1: Information sharing infrastructure and performance monitoring.

1. Regulations and policies are needed in order to overcome national and organisational sensitivities and confidentialities and develop an information sharing trust framework in Europe.
2. The new model for ATS data proposed by EUROCONTROL, together with the digitalisation of the industry, opens new data markets in which current levels of security need to be maintained. This requires further regulation and certification.

3. There is a need for better metrics & KPIs to measure the cyber-resilience of the system and to help monitor performance standards. The development of these metrics/KPIs should be the responsibility of ICAO or EASA.

The majority of respondents found this to be relevant or very relevant, and further stated that these should be the responsibility of Aviation Authority and of EASA and ICAO, where ICAO is considered as a leader on a global stage, but with rather slow processes.

Topic 2: Automation and AI/ML technologies in the aviation cybersecurity landscape.

1. AI and ML are at early stages of development within the ATM industry and therefore further R&D effort is needed in order to understand how these technologies can be safely deployed and certified.

2. These new technologies pose uncertain threats. R&D efforts are needed to understand to what extent cybersecurity can be 'automated' and managed with AI/ML (e.g. discovering vulnerabilities, speeding up responses to attacks, or autonomously patching).

3. Currently, there is a lack of required training and understanding of these new technologies by human operators, thus posing possible vulnerabilities.

The three topics were deemed very relevant by half of the respondents. The additional comments raise interesting points, as it has been pointed that “neither ML and AI aren't new nor is it ML/AI in the context of cybersecurity”, and that experts in ATM domains should be well trained before implementation of IA/ML. These two aspects incorporate the need of specific training to operate ML-based solutions and the importance of collaborating with other sectors where these solutions are more advanced in their level of implementation (e.g. automation)

Topic 3: Drones and UTM security.

1. The integrity of drone telemetry and information shared is key for safe and secure operations. R&D of efficient and effective tracking systems and cyber-secure data transfer systems is needed.

2. New UTM regulatory actions are needed in order to ensure the required levels of cybersecurity for drone operations.

3. The introduction of High-Altitude Long Endurance (HALE) operations (above 50 000ft) pose important operational and security risks for aircraft operating below.

4. The development of incident and accident analysis, and investigation frameworks, is needed in order to ensure adequate safety and security levels of drone operations during exceptional conditions (e.g. accidents, battery failures).

Three out of four topics were deemed very relevant, while the introduction of HALE operations was deemed not relevant in terms of posing the risks for aircraft operating below.

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These first three topics were chosen as top priority by more than 50% of respondents in the post-event survey (see Annex A).

Topic 4: Other research areas.

1. A self-strengthening aviation system through 'built-in security' iterations to face new threats in a more automated way ('anti-fragility') is needed.
2. Protection of the electromagnetic spectrum (e.g. spoofing and jamming) should remain high on the research agenda.
3. The air transport / ATM industry should take advantage of Commercial Off-The-Shelf (COTS) solutions as well as looking at other sectors (e.g. banking, nuclear).

3.3 TC2 Description and workshop conclusions

3.3.1 Description of challenge

Accurate and reliable trajectory prediction (TP) is a fundamental requirement to support the trajectory-based operations (TBO) paradigm. The lack of flight planning information sufficiently in advance and the mismatch between planned and flown trajectories caused by operational uncertainties from airports, ATC interventions, and 'hidden' flight plan data (e.g., cost indices, actual take-off weights) are important shortcomings of the state of the art, regarding pre-tactical and tactical trajectory prediction technologies. In addition, integrating predictions about meteorological conditions[1], including their uncertainties, could contribute to better trajectory predictions (see, for example, the Engage PhD, "Integrating weather prediction models into ATM planning".

Indeed, various stakeholders need different aspects of TP *across all phases* of operations, from the strategic, across the pre-tactical and to the tactical phases. User needs vary as a function of these purposes and their temporal focus.

New TP approaches, merging and analysing different sources of relevant flight information, are expected to increase TP robustness and support a seamless transition between tools supporting air traffic control (ATC) and air traffic flow and capacity management (ATFCM) in the different planning phases. The exploitation of historical data by means of machine learning, statistical signal processing, stochastic models and causal models can boost TP performance and enhance the TBO paradigm. A non-exhaustive list of relevant research topics includes the:

- use of machine-learning techniques to infer airspace users' (AUs') behaviour, intentions and preferences from historical data and enhance tactical and pre-tactical trajectory prediction; calibrating these against actual/revealed AU operational drivers (such as costs (route charges, fuel, delay); passenger connections and punctuality targets; crew rosters; maintenance and curfew restrictions);
- aggregation of probabilistic predictions into probabilistic traffic counts at a strategic and pre-tactical level thus reducing the uncertainty when predicting traffic volumes;
- integrating predictions about factors affecting flight planning and execution, including meteorological conditions, airspace configuration and route availability, also including the respective uncertainties associated with these predictions;
- development of tools for the identification of 'hotspots' and the evaluation of different ATFCM measures;
- bridging the gaps between the temporal phases of ATFCM.

[1] Note that Engage thematic challenge 3 is concerned with improving overall ATM system performance by providing better user-support tools based on improved meteorological products. Readers should be mindful of the different objectives of the two thematic challenges.

All of these developments could be integrated into the Network Manager's, ANSPs' and/or flight operations centres' 4D trajectory planning tools, leading to enhanced collaboration in trajectory management, such that capacity can be better matched to demand by a better anticipation of AU behaviour, including operations planning and flight plan filing, and such that AUs can benefit from ATM interventions better fitted to their business models.

One of the recent examples of the successful implementation of such tools in the operational environment is the Traffic Prediction Improvements (TPI) tool introduced by Maastricht Upper Area Control Centre, which is based on innovative machine-learning techniques to predict real-time flight routes and better manage traffic flows[2].

Robust demand forecast is a fundamental requirement to support the Trajectory-Based Operations paradigm and a key enabler of ATFCM service delivery. Network and capacity planning is continuously refined at different temporal planning horizons, from months to few minutes before operations. This implies using different forecasting methods adapted to the different sets of input data available at different times, each one with its associated uncertainty and granularity levels. This presents a series of challenges, and notably a lack of flight planning information sufficiently in advance – with a mismatch between planned and flown trajectories, caused by the operational context uncertainties identified above.

Current demand prediction tools are based on statistical observations, heuristic decision rules and/or simplified dynamic models, which fail to consider other important contextual flight attributes (e.g., airspace user specificity, meteorology). Additionally, the resulting forecast is often deterministic, without any quantification of the uncertainty of the prediction. These shortcomings limit the accuracy of the forecasts and create a gap between the different temporal phases of ATFCM, leading to inefficient or sub-optimal ATFCM measures.

Considering previous research in this field, sophisticated trajectory prediction models are often hindered by the need to estimate operational flight intentions, which might differ from one airspace user to another, and by aircraft type, etc. Certain sensitive information, such as the cost index, take-off weight or other unknown aircraft performance parameters also contribute to the problem. Additionally, much of past research has focused on the tactical planning phase, relying on flight plans, which may be available only a few hours before operations and can be subsequently modified, leading to mismatches between predicted and actual flown trajectories.

The increasing availability of data at different scales, together with recent advances in the fields of machine-learning, data analysis and visualisation, present opportunities to develop new modelling techniques to improve trajectory prediction performance and robustness by:

- the application of new modelling methods, such as machine-learning techniques, advanced statistical and/or causal modelling and statistical signal processing solely, or in combination with traditional methods (the reader is invited to refer to a range of such activities across the Engage PhDs and catalyst fund projects);

[2] https://www.eurocontrol.int/publications/traffic-prediction-improvements-tpi-factsheet-and-technical-documentation

- integrating and analysing different sources of endogenous and exogenous factors affecting flight planning and execution, including meteorological predictions, airspace configuration and capacity, and the uncertainty inherently associated with these predictions;
- inferring airspace users' behavioural drivers from historical data;
- engaging airspace users to collaborate and benefit from potential air traffic management interventions (better) fitting their business needs.

3.3.2 Workshop conclusions

This section consolidates conclusions from the first two workshops.

Different stakeholders in the aviation system use trajectory predictions with different objectives and timelines. These embrace demand assessment and capacity planning in ATFCM at the strategic, pre-tactical and tactical level, operations planning and execution by AUs across the same phases, conflict detection and resolution (i.e. separation management) for ATC, collision avoidance in certain safety nets, and performance monitoring.

For example, planning and decision-making by AUs at the pre-tactical and tactical levels (e.g. (most) flight plan filing; dispatch; self-separation and in-flight trajectory updates thereafter) and assessments made by (ATM) performance monitoring and/or target setting agencies, require *different* trajectory predictors. Owing to these diverse applications, requirements vary and hence the best TP implementation also varies depending on the purpose and prediction horizon.

Closer to flight execution, data become available that were not available in earlier planning phases: an example is the absence (at least from the ANSP/NM viewpoint) of (sufficient) flight plan data in the pre-tactical planning phases, when the Network Manager together with national service providers attempt to match airspace capacity with the anticipated demand. Accurate demand predictions are a central requirement in the demand-capacity balancing process. A smooth transition is desirable between all phases of the planning process as, for example, flight plan data and local restrictions become available. Understanding and, to a certain degree, predicting the behaviour of airspace users before flight plans are filed, goes a long way towards anticipating demand for airspace capacity. Studies have also revealed that the flight planning behaviour of different airlines is often very different in terms of when the first and last flight plans are filed, and to what degree the last-filed flight plan differs from the first-filed. This illustrates that differences between different AUs need to be considered.

The availability and quality of relevant data is a prerequisite for accurate TP. This concerns: physical access to clean data across a number of types and protocols; overcoming stakeholders' concerns regarding data sharing (e.g. confidentiality and competition issues); and, the implications for hardware/software (avionics, electronic flight bags (EFB), data link). Appropriately sharing trajectory data as widely as possible benefits both operations and research objectives, as opposed to only sharing data that allows the calculation of trajectories using specific TP implementations.

Trajectory predictors do not currently have access to the range of data that could benefit improved predictions: this includes trend data, as well as stakeholder preferences and intentions. Some of these missing data might be extracted from historical datasets. TP is also often 'blind' to operationally relevant information, for example leading to (very) high false alert rates for conflict detection systems such as medium-term conflict detection (MTCD) and short-term conflict alerts (STCAs). Tactical ATC interventions, for example flight-path shortening through radar vectoring, are not usually considered,

whereas a TP anticipating (or suggesting) controller interventions and conflict resolutions would be more powerful.

A significant challenge not only for TP but also for researchers attempting to improve this, is access to data, including historical surveillance and flight plan data, aircraft performance data, delay data, meteorological data and airspace-related data. A number of alternative sources have emerged, specifically those using ADS-B data (Flightradar24, OpenSky). In addition to using these datasets directly, some models have recently been proposed that use them to derive 'hidden' information, e.g. related to aircraft performance. Whilst these developments are encouraging, providing access to high quality, primary data and providing guidance as to their use, remains a vital concern for TP research.

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

1. Trajectory predictors supporting airborne self-separation: definition of requirements and concept development of enabling technologies;
2. Improved DCB: enhanced TP integrating uncertainty assessment, robust planning and cost-efficiency assessment at network level;
3. Data-driven approaches for understanding and predicting AU preferences and behaviours, (including 'hidden factors' such as the cost index or actual take-off weight) enabling improved NM operations; the calibration of such approaches;
4. Improving the transition between ATM phases (strategic, pre-tactical, tactical) through TP approaches that model and anticipate flight-relevant factors that typically only become available later than desired, e.g. the use of advanced meteorological models;
5. Integrating data sources and models not presently widely used in TP, including the modelling of prediction uncertainty;
6. Mapping requirements definition and concept development of data-driven TP in support of collaborative multi-sector CD&R;
7. Optimising and integrating local planning activities with a view to assess and communicate their network effects;
8. Improving data sharing and data access to satisfy AU, NM and ANSP technical and organisational requirements and expectations.

3.4 TC3 Description and workshop conclusions

3.4.1 Description of challenge

Weather is an integral part of ATM, especially in the light of increasing traffic levels, where weather conditions present a significant source of uncertainty in the planning process, and one of the major causes of disruption and consequent delay during operations. About 20-30% of total ATFM delay has been caused by weather in recent years, while this grew to 20-45% in the first six months of 2018, thus challenging the achievement of the Performance Scheme goals for the year. In addition, extreme weather phenomena such as hail, severe icing and lightning present significant hazards as they can inflict substantial damage to aircraft. As extreme weather events are becoming more frequent in Europe, and forecast certainty is apparently decreasing, ATM performance is negatively impacted.

This thematic challenge aims at understanding how ATM may benefit more from the advances in meteorology/atmospheric sciences, especially in the light of climate change and the weather uncertainty that it brings. This is a key issue in the current European ATM research arena because on the one hand, extreme weather patterns are changing with climate change and, on the other hand, the impact of weather on different parts of the ATM network and its stakeholders (e.g. airports, ANSPs, airlines, passengers, Network Manager) varies in the type and magnitude of disruption, and consequent costs. For example:

- Airports – different conditions (e.g. rain, fog, snow) can cause capacity reductions and even closures (see also the ACI policy brief[3] on climate adaptation by airports);
- En-route – winds impact aircraft speed, weather cells can cause ANSPs to change flights' trajectories, or impose regulations for more severe weather, etc;
- Airlines – trajectory changes[4], delays and schedule disruption occur, resulting in various types of cost (e.g. passenger reaccommodation);
- Network level – the Network Manager (NM) coordinates and circulates the information to all stakeholders regarding local weather impacts on flow management, without taking decisions on local weather-related actions, apart from facilitating network-level harmonisation; an overarching, reliable and shared view on weather is not yet fully in place in the European network. Initial testing of cross-border forecasts and ATFM procedures with five States (with related ANSPs and MET providers) took place in summer 2019.

Hence, meteorological information needs differ across stakeholders, either in the type of information, or in the useful time horizon and in the certainty/uncertainty that can be tolerated in the decision-

[3] https://store.aci.aero/wp-content/uploads/2018/10/Policy_brief_airports_adaption_climate_change_V6_WEB.pdf

[4] Improved trajectory prediction *per se* falls within the remit of Engage thematic challenge 2. Readers should be mindful of the different objectives of the two thematic challenges.

making processes. The time horizon may span from a few days to real-time, depending on the stakeholder and the function the stakeholder performs (e.g. ATC, or baggage handling at the airport). Furthermore, different forecast (and observation) resolutions are needed - a grid of 100 km^2 could be quite adequate for an ANSP, but lacks necessary detail for terminal manoeuvring/airport management. Another important component is the level of uncertainty that weather conditions impose. In the planning processes, higher uncertainty is tolerated, while in real time operations more certain information on the extent and trend of meteorological conditions is needed.

At present, the delivery and format of meteorological information provision is regulated by ICAO Annex 3, EASA and national regulations (in Europe). Regulated MET services and products[5] from certified MET ANSPs are quality controlled and are, in principle, free. In the USA, the National Weather Service provides a comprehensive set of forecasts, observations and tools *via* the Aviation Weather Center, and the Federal Aviation Authority deploys various weather-related decision-support tools aimed at more efficient air traffic management. In Europe, there are about 40 MET information service providers, some being certified by National Meteorological and Hydrological Services, some by air traffic service organisations, or a mixture of the two. Each has different responsibilities and cost structures. Commercial value-added services exist, and allow tailoring to user needs. These can be provided by a commercial MET provider or MET ANSP (for a fee).

The Pilot Common Project (EU 716/2014) and Regulation EU 2017/373 are calling for additional MET services, and there is a widespread belief that if action is not taken promptly, new climate conditions will pose ever greater challenges to all ATM stakeholders.

In fact, the number and the intensity of extreme weather events increased in recent decades in some areas of the globe including Europe (Hov *et al*., 2013). Damage is mostly caused by strong winds, hail and precipitation intensity. Studies suggest that higher precipitation intensity for northern Europe, dry-spell periods for southern Europe, high intensity and extreme precipitation are expected to become more frequent within the next 70 years. The increased frequency is estimated to be larger for more extreme events, but will vary considerably from region to region (*ibid*). For instance, Black *et al*. (2010) reported decreasing winter rainfall over southern Europe and the Middle East and increased rainfall further north caused by a poleward shift of the North Atlantic storm track.

Long-term changes in European storminess are not very clear and sometimes show conflicting results. Some studies show a strong multi-decadal variability (Alexandersson *et al*., 2000; Bärring and von Storch, 2004; Wang *et al*., 2009), and analyses of extreme wind speeds highlight significant upward trends in central, northern and western Europe (Donat *et al*., 2011b; Brönnimann *et al*., 2012). Models under scenarios with increasing greenhouse gas concentrations indicate an increase in the number of severe storms in north-western and central Europe, which is also in accordance with other simulation results (Beniston *et al*., 2007). These simulations also suggest a significant increase in cyclone intensity and the number of intense cyclones over northwest, central and western Europe, under future climate conditions (Leckebusch *et al*., 2006, 2008; Pinto *et al*., 2009; Ulbrich *et al*., 2009). A belt stretching from the United Kingdom to Poland will experience an increase in extreme storminess and wind speed, while

[5] MET products refer to different types of meteorological information, such as forecasts, observations, now-casts.

southern Europe and the Mediterranean will rather see a decrease in strong winds (Leckebusch *et al*., 2006; Donat *et al*., 2011a).

It must be recognised that recent years have witnessed important improvements in observational (e.g., satellites, light detection and ranging (LIDAR), Global Navigation Satellite System (GNSS) receivers) and numerical weather prediction (NWP) models in the atmospheric sciences (e.g., models for air quality in megacities that consider topography and resolution of under 100m). However, little has yet filtered down to the ATM world. Several workshops and MET-related projects came to similar conclusions: it is important to bring ANSPs, airlines, academics, MET service providers and atmospheric scientists together to better understand the effects and requirements of mitigation actions to convective, winter and hazardous weather at trajectory, network and airport levels. In some cases, tools and know-how exist, in others better models and outputs became available but are not exactly what ATM needs.

Thus, the initial step towards delivering the improved MET information needed for more efficient air traffic management consists of learning about improvements in the atmospheric sciences, about ATM needs in the light of the uncertainty that weather imposes on the network (and related uncertainty management), possible educational needs to foster better understanding between the two scientific and operational groups and, possibly, associated regulatory issues. The ultimate goal of this thematic challenge is therefore to define further research and operational needs regarding the use of weather information for more efficient ATM.

3.4.2 Workshop conclusions

This section consolidates conclusions from the first two workshops.

MET-related research should enhance situational awareness of MET conditions for all ATM stakeholders, using state-of-the-art MET products. MET provision in Europe is fragmented, as each state is responsible for the provision for its territory. This is one of the reasons for the lack of a consistent and agreed weather 'picture' for ATM in Europe. To overcome this issue, and to reduce the impact of weather on delays, the NM and EUMETNET trialled a procedure with the goal of introducing a common weather picture and to better cope with adverse weather and the consequent delays. The trial involved the NM, DSNA, NATS, DFS and MUAC, and EUMETNET comprising: the Met Office (UK), KNMI (Netherlands), Skeyes (Belgium), Météo France and Deutsche Wetterdienst (Germany). As the impact of weather is usually worse in the period from May to July, as the high traffic demand coincides with summer convection, the trial took place during the summer season.

The procedure was based on existing technology, with the goal to improve collaboration, planning and dissemination of information with the ultimate intention of reducing the number of weather regulations, increasing lead times of regulation application and increasing stability. The MET providers established a common weather picture over the agreed geographical area, for the pre-tactical period (Day-1), where it was concluded that a 'consistent' view of the weather collaboratively agreed between stakeholders is more important than a 'perfect' view of the weather. An important part of the trial was the need for simple communication between meteorologists and controllers. With that in mind, EUMETNET developed a coloured risk matrix across two dimensions - probability/confidence and distribution/frequency, categorising the events into N (none), L (low), M (medium), H (high) and VH (very high), where only H and VH are of interest for the impact on the network. That forecast was then shared with the participating ANSPs and any H or VH events would trigger the teleconference to agree on the plan of action for the next day (i.e. 'red' coding leads to action).

The procedure was assessed as a good first step, with the following benefits: increased situational awareness - as forecast and insight from other ANSPs gave context on what to expect the next day; the risk matrix allowed for clear decision making as everyone knew when collaboration was expected; the triggers (H or VH) were about right; some issues (prompting further discussion) emerged regarding some medium-risk occasions; teleconferences gave a wider network overview; additional participants were invited when needed, which generated positive feedback. The plan is to continue this collaboration, extending the geographical scope, and then to work on including jet streams, more tactical forecasts and collaborations. This common weather picture should be available in the Network Operations Portal, i.e. in an easily accessible place. The Engage catalyst fund project, "MET enhanced ATFCM", aims to develop a MET product for convection (multi-model/multi-parameter) to support ATFCM decision making, ultimately leading to optimised en-route weather regulations.

Regarding common awareness, the OPAS project aims to develop an alert product for sulphur dioxide, which is often used as a proxy for the presence of volcanic ash in the atmosphere. Currently, the Volcanic Ash Advisory Centers do not need SO_2 information. However, there are discussions to include it in ICAO considerations around volcanic ash alerting for aviation.

Another aspect of MET-related situational awareness relates to the information available to pilots, which EASA has been addressing in recent years. A strategy paper on weather information for pilots was published in March 2018 (EASA, 2018a), and lists nine, non-binding recommendations to be taken forward by the "Best intervention strategy" proposal. EASA also published the results of a survey on the use of electronic flight bags and installed weather applications to facilitate in-flight weather updates to the cockpit by the airlines (EASA, 2018b). All survey respondents had EFBs, with about half having weather applications for pre-flight briefings, while for in-flight briefing, including in-flight updates, only 15% of respondents had them included in EFBs (whilst many planned to include some functionalities in the next five years).

Currently, the trend in MET research is focused on ensemble prediction systems. Thus, in the next 5-10 years we should expect MET products to be realised as ensembles, providing measures of uncertainty in different atmospheric variables. A long-term educational and communication effort should be undertaken so that ATM stakeholders are prepared to understand and interpret these new MET products, in order to incorporate them into their decision-making processes, taking advantage of better information. The Engage catalyst fund project, "PSA-Met", and the Engage PhD, "Stormy", both address ensemble forecasts and the development of decision-support tools for stochastic storm avoidance, using different methods for storm evolution prediction.

The climate impacts of aviation, comprise more than CO2 impacts – such as NOx, ozone and contrails. Aviation emissions impact the climate and more research is needed to establish these quantitative effects and whether there is (further) potential for mitigation actions. The Aviation and Global Atmosphere report by the Intergovernmental Panel on Climate Change lists the different components of aviation emissions. There is consensus on the direction of impact of these components, but there is still no consensus on their magnitude. An interesting point, is that some regions of the atmosphere are more sensitive to certain types of emissions than others, and negative effects can be propagated to larger regions and last longer. The climate impact of non-CO2 emissions depends on the time and position of aircraft, actual weather conditions (processes, transport pathways, temperature and humidity) and background (emissions) concentrations. This points to the importance of having 4D (weather-like) forecasts of environmental impact, which could enable trajectory planning to account for these environmental impacts.

MET products can be classified along two dimensions: spatial and temporal resolution. In terms of spatial resolution, forecasts can be cast as global (resolution of about 1 degree), limited-area models (covering regions such as Europe, resolution in terms of tens of kilometres), and of very high-resolution (smaller areas, such as terminal manoeuvring areas, resolution of hundreds of metres). In terms of temporal resolution, there are long- (about 1 week), medium- (about 1 day), short- (about 3-6 hours), and very short-range (about 1 hour) forecasts. Both the temporal and spatial resolution are important depending on the stakeholder application. For example, the NM is interested in medium-range / limited-area forecasts; dispatchers, in short-range / limited areas; pilots/controllers, in very short-range / very high resolution when facing storms; airports, in very short-range / very high-resolution, etc.

The higher the resolution, the forecast becomes more challenging. NWPs alone are not sufficient for this type of product, and call for data assimilation of the observed values of varied atmospheric characteristics (e.g. lightning, deep convection). *In situ* sensors and sensor networks that collect and deliver information for forecasting are needed. The aggregation of different sources of data for blended ensemble forecasts in the very high-resolution, very short-range scales seems to be the trend for the next 10 years.

The Engage catalyst fund project, “CARGO”, is studying the use of low cost GNSS receivers, and lightning detectors, to develop nowcasting forecasts for convection at very short range / very high resolution. Input from different sensors will be fed into a neural network model. The Engage PhD, “IWA”, is evaluating the impact of weather conditions on route planning in the TMA. Probabilistic models are to be applied on the weather data, and mathematical tools to be used to develop a prototype for decision-making.

Often-cited barriers to the progress of MET and MET/ATM research are the inadequacy of research funding available to the MET offices (only partial funding), and fragmented provision of MET products for aviation (coupled with regulatory and sovereignty matters). Further important barriers revolve around the trust the ATM users have in available MET products, and not particularly high usage in operational decision-making. This points to the two underlying issues:

1. fitness of purpose of MET products (e.g. medium-range, limited-area forecasts are of little practical use to airport tower supervisors, while the very high-resolution, very short-range forecasts would be more easily included in this decision-making process);

2. ATM stakeholder knowledge of the available MET products, especially on the characteristics and meaning of MET products being developed.

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

1. Very high-resolution, very short-range forecasts using numerical weather prediction models and observational data assimilation;
2. Quantifying the sensitivity of operational processes to MET uncertainty, comparing these with other sources of uncertainty;
3. Incorporation of ensemble weather information into decision-support tools, adapted for different ATM stakeholders;
4. Accurate prediction of weather conditions (e.g. visibility, glide-path wind) influencing airport arrival and departure operations;
5. Consolidation of climate risk assessment methodologies for airports;
6. Creating a climate forecast 'baseline' for aviation from the IPCC UN panel report;
7. Developing quality EU-wide weather information in the tactical air traffic control context (an integrated, pre-tactical EU-wide picture is beginning to be developed);
8. Forecasters and end-users (e.g. controllers and pilots) co-developing products that are easy to interpret in terms of the impact weather will have on such users (e.g. airspace, flights);
9. Transferring knowledge to end-users (e.g. controllers and pilots), reflecting that the state of the art in modelling is moving towards probabilistic approaches;
10. Producing an EU-wide, one-stop repository of MET data, addressing data harmonisation and scoping the archiving of such data.

3.5 TC4 Description and workshop conclusions

3.5.1 Description of challenge

Air traffic management (ATM) is an example of a system where demand often exceeds capacity. In Europe, for a flight flying from a given origin to a destination, a shortfall in either en-route capacity (e.g. insufficient controllers to handle the flight) or at the destination (e.g. insufficient runway capacity to receive the flight), results in the flight being delayed at the origin until an appropriate trajectory and tactical departure slot are available. Each year, such delays generate large costs for the airspace users (AUs, airlines) and passengers. During such capacity constraints, challenges remain regarding, inter alia, the trade-off between minimising the delay in the network as a whole and the delay for given airspace users. This thematic challenge explores the design of new market mechanisms for the (re-)allocation of trajectories/routes and slots (often linked resources) to airlines in the tactical phase. "Market" mechanism does not necessarily imply the use of money as a medium for transactions. Moving beyond first-planned, first-served (FPFS) principles, matching markets, centralised batch auctions, primary and secondary markets (double auction or bilateral exchanges) may each bring advantages. The challenge also seeks to explore better ways to predict the actual behaviour of stakeholders (airspace users in particular), compared with behaviours predicted by classical models, also taking into account that decisions are often made in the context of uncertainty. Such uncertainty may be aleatory (due to chance, such as weather) or epistemic (due to lack of information). The challenge poses questions such as: which types of mechanism are likely to work best in tactical slot and trajectory management[6], under different types of uncertainty and information sharing? Which mechanisms are more robust against behavioural biases ('irrationalities'[7]) and likely to reach stable and efficient solutions more quickly, e.g. without leaving unused slots? How can we equitably build on existing SESAR practices, such as Enhanced Slot Swapping, and planned SESAR functionalities such as the User-Driven Prioritisation Process (UDPP)?

Several SESAR exploratory research (ER) projects (e.g., SATURN, ACCESS, COCTA) have advanced the market mechanism state of the art already, exploring ways in which the efficiency of existing solutions might be improved, including market-based demand-management mechanisms for air traffic flow management (Bolic et al., 2017; Castelli et al., 2011), auctioning for strategic airport slots (De Neufville and Odoni, 2013; Herranz et al., 2015), and controlling tactical delay distributions to minimise propagated delay and increase adherence to (strategic) airport slots at coordinated airports (Ivanov et al., 2017). This research has been complemented by findings in ER projects such as APACHE, INTUIT and Vista. Further development opportunities lie ahead, in that modelling in these domains variously investigates the optimal use of limited capacities but (necessarily) assumes full rationality, for example regarding flight scheduling and demand management that might "create opportunities for strategic behaviours from the airlines, i.e., potential incentives to provide scheduling inputs that do not reflect

[6] Improved trajectory prediction per se falls within the remit of Engage thematic challenge 2. Readers should be mindful of the different objectives of the two thematic challenges.

[7] The terms 'arational' and 'non-rational' are also often used.

their true preferences in order to gain a strategic advantage over their competitors" (Jacquillat and Odoni, 2018). Regarding airport capacity and demand management, these authors further comment that "abstractions and simplifications of reality that necessarily underlie these mathematical and simulation models cannot fully capture all the operating complexities found in practice". In a comprehensive review comparing and contrasting the operations research and economics perspectives in ATM, it is concluded that "significant opportunities exist to [...] extend the scope of economic studies to integrate more realistic models of flight scheduling and airport operations [...] addressing them incrementally would enable the development of cross-disciplinary approaches to airport demand management and more effective congestion mitigation policies" (Gillen et al., 2016). Indeed, further work in this area has modelled slot allocation efficiency and schedule displacement, stressing the importance of the complementary use of (slot) optimisation tools, challenging current views on constraints and boundary conditions (Ribeiro et al., 2018, 2019a, 2019b).

Approaches and methodologies applied to (strategic) airport slots are often of value, with transferable insights into the tactical context, although airport slots per se are not in scope for this thematic challenge. Let us thus turn to a major tactical example. SESAR continues to develop UDPP to achieve additional flexibility for airspace users to adapt their operations in a more cost-efficient manner. This makes use of mature mechanisms such as Enhanced Slot Swapping (deployed in 2017) and continues to validate mechanisms such as Fleet Delay Reordering and Selective Flight Protection (Pilon et al., 2016). It is also exploring future options for even greater flexibility regarding cost minimisation and equity for 'low volume' AUs with less market power, although integration of accurate airline decision-making and cost models in this context remains a challenge, and the best models to date assume full rationality and utility maximisation (Ruiz et al., 2017, 2019a). Other mechanisms that enhance first-planned, first-served principles (as implemented, for example, in Europe though the computer-assisted slot allocation (CASA) mechanism) have been explored, such as the mitigation of interacting regulations (Ruiz et al., 2019b) and adapting allocations of empty slots in sequences (Ruiz et al., 2019c), both discussing the impacts on delay reduction, fairness and equitability.

A number of economic models applied in ATM (and air transport) are normative, such as Nash equilibria and linear programming. They make several assumptions about agent rationality that do not always work as expected predictors of behaviour. This is because real decisions are often made by human beings, or at least with human intervention, and are not fully 'rational', in the sense of adopting the solution suggested by some type of optimisation process. Behavioural science in general, and behavioural economics in particular, may bring complementary solutions to ATM in order to better predict actual behaviour in the network. Behavioural economics is based on a number of related principles, examples of which are summarised in Figure 3.

Figure 3. Examples of behavioural economic principles in the context of ATM.

In loss aversion, losses have more disutility than gains have utility, typically by a factor of about two. With endowment effects, the value attributed to, say, a slot already owned would be higher compared to the value attributed to that exact slot when not yet owned (the 'later' time component is not usually a feature of the pure endowment effect, but is indicated here for purposes of trading realism.) The specific example given for the path dependency is also known as the 'sunk-cost' fallacy. In future discounting, it is observed that the value of a good depends on when it is consumed: people tend to discount the future heavily, putting a very high value on the present. Furthermore, prospect theory (Kahneman and Tversky, 1979) describes risk-aversion in the gain domain (when things are going well) and risk-seeking behaviour in the loss domain, and establishes that such effects depend on our baseline, i.e. are reference-point dependent.

These considerations may be important drivers of different airspace user responses under different conditions of relative loss during the imposition of tactical slot delays. Behavioural economics often seeks to 'nudge' the agent into making the 'right' choice, by making it easier, whilst still leaving all choices available. In ATM, we have various key performance areas (KPAs), through which to establish different kinds of 'right'. Whilst more broadly, behavioural science may consider aspects such as airline general 'beliefs' (or 'cultures', e.g. that a certain type of action results in a certain type of delay), behavioural economics tends to focus more specifically on understanding financial trade-offs, taking into account that agent rationality is 'bounded' (such agents are not willing or capable of solving complex optimisation problems, as they are assumed to in normative models predicting behaviour). Whilst classically, market forces are often assumed to establish rationality and, ultimately, to produce a predictable equilibrium, this is often not the case. Human beings often have to take mental shortcuts, and use heuristics, as cognitive resources are scarce. The resulting biases and heuristics, including over-confidence, can lead to suboptimal decision-making. Behavioural science, with behavioural economics, thus focuses on what agents actually do, rather than what they 'should' do, and is driven by descriptive models.

This thematic challenge may thus investigate the extent to which ATM can move from objective functions to 'subjective' functions, i.e. that take account of 'irrational' agents. In a 2014 review, Whitehead et al. (2014) state that "the behavioural sciences are clearly having a global impact on public policy initiatives [...] 136 states have seen the new behavioural sciences have some effect on aspects of public policy delivery in some part of their territory [...] 51 states have developed centrally directed policy initiatives that have been influenced by the new behavioural sciences." Several ATM stakeholders have expressed a need to take advantage of behavioural science to improve operational predictability. There are limited examples considering actual human behaviour in the context of wider transport planning and environmental policy (e.g., Avineri, 2012; Garcia-Sierra et al., 2015), and few formal considerations of the applications of behavioural science in ATM.

Classical modelling approaches from economics and operations research, such as game theory and linear programming, have been used extensively to assess the impact of flight prioritisation mechanisms. The strong assumptions behind these approaches, such as that of agent rationality, make such models unrealistic in certain circumstances. This may result in researchers overlooking the risks and unintended consequences of certain mechanisms, when stakeholder behaviour departs from such assumptions. Agent-based modelling (ABM) offers one way forward to address such issues. It allows the observation of emergent behaviour arising from agents' interactions in a bottom-up process, substantially reducing several disadvantages of traditional models, such as strong hypothesis dependency.

The integration of data science (including, but not limited to, methods such ABM and machine learning) with behavioural economics, is often referred to as computational behavioural economics – it provides a natural framework for gaining new insights into human and institutional behaviour from operational simulation models. An important area of research currently being addressed by Nommon Solutions and Technologies (Engage catalyst fund project "Exploring future UDPP concepts through computational behavioural economics") is the generation of a specific assessment framework to evaluate the performance of different flight prioritisation and trajectory allocation mechanisms. The assessment framework generated is focused on certain KPAs, corresponding to the impacts that may be influenced by the application of such allocation mechanisms. Particularly interesting, are certain areas that have not been widely considered in previous studies and are essential to accurately represent and evaluate these mechanisms, such as equity and robustness to unexpected behaviours.

Behavioural science is not a panacea with regard to resolving certain shortcomings of the classical approaches to operations research, and assumptions of utility maximisation, for example, that still serve the ATM community well. Nor can it model the full scope of agent subjectivity. Rather, this thematic challenge seeks, inter alia, to identify and explore key areas in which behavioural science may advance the state of the art regarding ATM modelling, complementarily bridging existing gaps. This will involve identifying methods and solutions where an absence of behavioural modelling is particularly likely to compromise model usefulness and, where possible, to collect evidence of such (anticipated) shortfalls.

More broadly, can we identify the first steps towards improved tools to better manage the costs of delay, and of uncertainty, and to better incentivise behaviour that benefits the network, in the wider context of tactical slot and trajectory allocation? For example, ATFM slot swapping has previously only been achievable through intra-airline swaps, used by airlines to prioritise flights, with the typical objective of minimising overall (delay) costs, which may be driven by passenger connectivities, crew hour restrictions, maintenance requirements, or night-time curfews on final rotations. Airspace users wish to keep these operational costs confidential. This is currently seen as a barrier to inter-airline slot swapping.

What new technologies might be appropriate to support the negotiation of tactical contracts? For example, might cryptoeconomic tools[8] have a role to play in delivering 'smart'/'private' contracts? Specifically, could blockchain technology and secure multi-party computation extend existing UDPP solutions, offering the possibility to protect the participating AUs' sensitive information? Such technologies may allow for secure, auditable transactions without the need for a central broker, where stakeholders would be able to enter slot-swapping transactions without disclosing information to other participants. By demonstrating the feasibility of a privacy-preserving platform for swapping ATFM slots, the foundations could be laid for the development of tools that may contribute to better use of existing resources at airports, improved efficiency for airlines and reduced delays for passengers.

[8] Note that vulnerabilities and global security of the CNS/ATM system falls within the remit of Engage thematic challenge 1. Readers should be mindful of the different objectives of the two thematic challenges.

From a user-acceptability perspective, could such tools deploy a centralised market with real money, or would only 'credits' be acceptable? Furthermore, it remains a particular challenge to investigate the extent to which such tools may anticipate and control for 'irrational' effects, and become automated features of future slot allocation and management procedures, based on stated user preferences for priorities and route choices.

3.5.2 Workshop conclusions

This section consolidates conclusions from the first two workshops.

Early UDPP developments introduced Enhanced Slot Swapping (ESS) and UDPP Departure, which extended the options for AUs to rearrange flights, including the multi-swap feature. More recently, other UDPP mechanisms allowing higher levels of flexibility have been proposed, such as Fleet Delay Reordering (formerly 'Fleet Delay Apportionment'), where each AU can decide how to distribute the delay it must absorb among its flights in a hotspot, and Selective Flight Protection (SFP), whereby AUs can voluntarily suspend certain flights (i.e., move them later in a departure sequence) and protect others (Pilon et al., 2016).

In addition to the concepts developed within the context of SESAR, a variety of allocation mechanisms have been investigated and proposed in the literature. The proposed mechanisms place emphasis on the assignment of ATFM slots, on the priorities assigned to flights in case of disruption, on potential rerouting paths, or multiple such criteria. Depending on the operational nature underpinning the prioritisation concept, the different mechanisms can be divided into three groups. Firstly, the mechanisms concerning the implementation of several operational standards and regulations fall inside the rule-based category. Secondly, there are several mechanisms that rely on the use of money and the forces of supply and demand to determine the optimal solution in situations where different entities are competing for scarce resources: monetary, market-based mechanisms.

Finally, and in part due to the reluctance of many AUs to use real money, some mechanisms make use of virtual currencies, such as credits, to achieve certain prioritisation strategies: non-monetary, market-based mechanisms. Extended-SFP (ESFP) is such a concept proposed in the scope of SESAR with new prioritisation features. The potential advantage is the ability to also provide flexibility to AUs with a low number of flights involved in a regulation, thus increasing the equity of the system (Ruiz et al., 2019a). It is based on the use of a virtual currency without monetary value: '(delay) credits'. Several mechanisms are summarised in Figure 4.

NextGen (the US analogue of the SESAR programme) originally proposed BPBS (Figure 4), providing priority to best performing aircraft in enhanced operations. Centralised Peak Loading Pricing (CPLP) was proposed by Bolić et al. (2017); it broadly represents an ATM analogue of toll roads, whereby a variable price is used to control demand. Credit Points for Re-routing extends the credit-based paradigm to route prioritisation (Sheth and Gutierrez-Nolasco, 2010). It deploys the ability of AUs to fly optional routes, prioritising each one with credit points, received daily as a fixed amount, based on the volume of their operations.

Mechanism Name	Operational Basis	Phase of Application	Credits can be used on a later day?	Currently in use?
First Planned First Served (FPFS)	Rule-based	Tactical	N/A	Yes
UDPP - Enhanced Slot Swapping (ESS)	Rule-based	Tactical	N/A	Yes
UDPP - Selective Flight Protection (SFP)	Rule-based	Tactical	N/A	No
Best Performing Best Served (BPBS)	Rule-based	Strategic / Tactical	N/A	No
Auction (primary or secondary)	Market Monetary	Strategic / Tactical	N/A	No
Congestion Pricing (CPLP)	Market Monetary	Strategic	N/A	No
Route Contracts (COCTA)	Market Monetary	Strategic	N/A	No
UDPP - Extended-SFP (ESFP)	Market Non-Monetary	Pre-Tactical / Tactical	Yes	No
Credits Points for Re-routing	Market Non-Monetary	Strategic / Tactical	No	No

Figure 4. Summary of flight prioritisation mechanisms (Courtesy Nommon Solutions and Technologies)

Assessing the benefit of these mechanisms across different stakeholders (airlines; passengers; airports; ANSPs, the Network Manager), and the relative importance of KPAs across these stakeholders, it is clear that the corresponding benefits and priorities are distinctly heterogeneous. Monetary mechanisms (and auctions) may be expected to benefit larger AUs more than smaller ones, as may BPBS (although this depends on underlying funding mechanisms and precise definitions of 'best served'), thus delivering low equity. Credit accumulation needs to be carefully controlled so as not to prejudice against smaller AUs (see also Ruiz et al., 2019a), but may then indeed be equitable for AUs, although most susceptible to 'irrationality' effects. Such effects and biases may potentially be measured – in future research – relative to monetary equilibria. The equity of credit-based systems between airport contexts is more of a challenging prospect, it seems. Whilst AUs value simple mechanisms and flexibility in particular, and mechanisms offering the possibility for change as late as possible, airports and ANSPs more typically place higher value on predictability (e.g. regarding gate changes and sectorisations, respectively), disfavour late volatility in the system, and value increased predictability furnished through pre-emptive, congestion-alleviating mechanisms. Regarding AUs' differential prioritisation on KPAs, they are clearly profit-motivated and wish to drive metrics that reflect passenger loyalty and hence market share: cost and punctuality. Airports and ANSPs are likely subject to drivers of customer service delivery to the AUs (and passengers), in addition to often complex regulatory constraints regarding cost efficiencies. Airports are (currently) most susceptible to public pressure regarding environmental impacts.

There is, however, no unique way to define equity and fairness, since these may or may not invoke monetary value, and may depend on the stakeholder perspective and impacts, both at the local and network levels. Within the context of UDPP, equity is defined such that the action of one AU does not generate a direct negative impact (i.e., increase the delay) of other AU's flight(s). Within the context of first-planned, first-served, fairness is defined such that the original sequence of planned flights is preserved. Improved definitions of equity and fairness are needed, potentially differentiating or consolidating the two terms, examining the definitions and trade-offs across different stakeholders (e.g. airports treating all flights equally, unlike airlines), plus the trade-offs with flexibility and, indeed, more mature definitions of the latter.

Further work is also needed on the precise definition of the 'best' trajectory[8], by stakeholder type, not only across airspace user types. Greater elucidation is required of the need to adopt a compromise between individual rationality, budget balance, allocative efficiency and incentive compatibility (see Castelli et al., 2011) in the design of new mechanisms. This should build on existing exploratory research in SESAR examining the trade-offs between centralised and decentralised markets. As raised above, part of the move towards improved models of stakeholder behaviour could assess gaming, and mature the state of the art advanced by projects such as AeroGame[9], which investigated how the research domain of serious games can support change in ATM. It is necessary to model more realistic human interactions in a multi-stakeholder, complex socio-technical environment, rather than in highly constrained and limited simulation environments, and to determine which (incentive) solutions are best in terms of non-manipulability (Schummer and Abizada, 2017; Schummer and Vohra, 2013).

The robustness of (tactical) slot allocation mechanisms and airspace users' choice of flight plan as a function of time is made more difficult to predict in the context of uncertainty from exogenous factors and the AU's response to the evolving traffic situation as they adapt from the originally-filed flight plan. Airspace user cost functions need to be taken into account, and may be usefully framed in terms of flexibility characterisations, such as elasticity functions and 'not before' and 'not later than' departure rules. Such functions and rules could be deployed to empower airspace users to make better choices. Additional investigation of the potential role of ANSPs coordinating with the Network Manager to manage tactical demand (and route choices) is required, building on the work of COCTA, for example, assessing the impacts of uncertainty and disturbance, and the implications for policy recommendations regarding the Single European Sky Performance Scheme. Barriers to progressing the state of the art include the calibration and validation of new models such as those identified above, and obtaining quality stakeholder cooperation and buy-in. This might be overcome by running models and tools in shadow-mode, with usable and practical user interfaces, also demonstrating their value in terms of metrics such as predictions of (sector) overloads, delays and delay costs, and valuations of equity, fairness and efficiency. Data collection quality could be improved through the use of stated preference techniques, commonly deployed in socio-economic and psychological research, and sensitivity analyses would need to be run to test model and tool efficacies. Capturing gaming behaviours often requires projective techniques.

The introduction of standardised, integrated schedule recovery actions in tactical airline operations, based on microscopic stochastic process chains, with the primary objective of minimising overall network costs, may present a valuable way forward for developing a human-in-the-loop (HITL) decision-support system for airline operations controllers, at the network level. The tactical control of network effects had so far not been explored in a holistic manner. However, these issues are being addressed by the Engage PhD "Stochastic control of tactical airline operations in hub airport networks". Most of the literature has taken only individual aspects into focus, such as the accurate prediction of total turnaround times with stochastic process parameters (e.g. Oreschko et al., 2012) and the adjustment of block times (Kang and Hansen, 2017).

[9] https://www.sesarju.eu/newsroom/brochures-publications/aerogame

Of particular interest, is the fact that over multiple, partially parallel aircraft rotations, prioritisation processes may appear externally 'irrational'. This again links in particular with issues of scale and of cost efficiency.

Behavioural science could be used to better capture 'irrational' (arational, non-normative) behaviour from airlines in future, and build improved (agent) models, for example in terms of (tactical) routing and slot choices. This could deliver improved forecasting and traffic demand tools for ANSPs, and better predict behaviour under UDPP (for example) by validating key prospect theory principles, such as loss framing, risk-seeking behaviour under loss, and endowment effects. Capturing aleatory effects in agents, for choices with similar utilities/prospects, is also a challenge. New market designs for the allocation, and trading, of tactical slots may support potential future mechanisms for slot swapping and trading between different airlines.

Key to such progress will be understanding ways to more effectively manage airspace user cooperation and motivation, how these vary by airline type, and whether incentives or penalties work better. Is the better underlying driver of behaviour cooperation or competition, and can social norms be used to make airline behaviour more collaborative?

A key objective is to offer airspace users improved choice, whilst avoiding undesirable behaviours, such as gaming of the system. Improved application of interventions in the ATM context may draw on the 'mindspace' approach elaborated by Dolan et al. (2012), and earlier investigations already applied to ATC based on the theory of planned behaviour (Cook and Tanner, 2008).

Machine learning in general, and reinforcement learning in particular (exploring the corresponding behavioural incentives), may provide a useful approach to investigating collaboration policies that enhance exchanges between agents in order to maximise performance in given operational contexts (such as airport operations), and across diverse, agentified stakeholders.

If new styles and motifs of action emerge (which may appear locally 'bad', but are in fact globally 'good'), it is important to maintain the interpretability of the outputs from such virtual environments, such that 'irrational' behaviour is not replaced with opaque behaviour, and potential policy recommendations (e.g. for enhancing stakeholder cooperation), and tools, are both validated and understood.

Fundamentally, it is also clear that unexploited capacity remains, and it is still possible to make better use of existing capacity without having to invent solutions that are radically different from those currently in use. Opportunities remain for the application of mathematical/analytical models to further evaluate CASA enhancements, for example by relaxing selected, current boundary conditions and constraints, which may still yield significant benefits.

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

1. Incorporating behavioural science methods into improved traffic demand and distribution predictor tools for ANSPs and UDPP;
2. Assessing if incentives or penalties work as better drivers of behaviour: whether social norms can be used to improve collaboration;
3. Considering specific incentives for diverse stakeholders to collaborate (e.g. re. implementing flight prioritisation mechanisms) and what KPIs could be used to measure cross-stakeholder integration;
4. Predicting and avoiding undesirable behaviour, such as gaming, in ATM allocation mechanisms;
5. Building a better understanding of 'equity' and 'fairness', plus the trade-offs across different stakeholders, and with 'flexibility' and 'access' metrics;
6. Extending KPA trade-offs to consider: (i) particular stakeholder sub-groups, such as low-volume airspace users c.f. hub carriers, and connecting c.f. non-connecting passengers; and, (ii) effects over time and space (such as decaying or improving equity);
7. Improving assessments of uncertainty and disturbance, both exogenous (e.g. in model environments) and endogenous (e.g. to agents) – better quantifying models' and mechanisms' robustness;
8. Improving the contextualisation of new mechanisms for policy recommendations, ensuring that model outputs are appropriately transparent and validated;
9. Identifying emergent (positive and negative) effects of mechanism design, potentially developing improved measures of system complexity and resilience;
10. Running models and tools in shadow-mode, with practical user interfaces and values in output metrics (e.g. costs, overloads).

3.6 Technical workshop conclusions

3.6.1 Building passenger itineraries 1

The workshop contributed to identify the need of passengers in two different environments: detailed modelling of operations at a given airport to consider passengers connectivity, airlines' behaviour (e.g., waiting for passengers), and airport and ground operations (e.g., gate assignment to minimise passenger missed connections); and network-wide modelling of passenger itineraries with a higher focus on better capturing the cost of delay functions of airlines. Possible synergies between PhD students, considering the two previously mentioned uses of passenger data, were identified.

The overview of approaches to passenger itineraries generation followed by the University of Westminster in previous projects was considered useful by the participants. During the workshop the considerations of different algorithms and approaches, and some technical implementation activities were conducted. It was agreed that the PhD students would continue these activities independently with interactions between them (and with Engage) as required.

3.6.2 Building passenger itineraries 2

This remote workshop was conducted as a follow up of the first one in order to assess the progress done by the PhD students on this topic, to identify potential further needs. The meeting allowed the students to present their work on passengers data to their peers. Between the two workshops, the students who required the passenger itineraries to model operations of airlines at airports had developed models and were collaborating with stakeholders to gather and calibrate their data. The potential need of further datasets beyond passenger itineraries such as crew rosters was highlighted.

3.6.3 Technical session on access to EUROCONTROL's data sources

The EUROCONTROL presented the data available in the R&D archive, and how to obtain access to the data. The data available covers:

1. two years old, covering four months a year (March, June, September, December);
2. flight data, having filed and actual trajectories, in two formats (waypoints and segments);
3. airspace data on Flight Information Regions and AUAs, where AUAs cover different terminal and airport control airspaces.

3.6.4 SJU's ER & IR MET and ENV workshop

The IR and ER project leaders presented the goals of their projects. The discussion revolved around what each project is developing, to what accuracy level and how each can benefit from collaboration, and having in mind how to proceed to higher TRL levels after the project completion. The IR projects deal mostly with the MET tools for airports, thus looking for MET/ENV products that are applicable in this environment. The ER projects identified synergies and points for further collaboration.

An interesting point arose as several projects are looking into definition of different environmental (and MET) indicators, which can be a good starting point for enriching the environmental performance assessment in the future SESAR partnership (i.e. adding to the current fuel burn metrics). This has been highlighted as a topic for further discussion between these projects and the SJU's performance assessment team, to be considered after the projects had time to progress on their work.

4 Lessons learned

4.1 Specific lessons learned (by thematic challenge)

4.1.1 TC1

Workshop scheduling was affected by the pandemic situation. After postponing the original date for an on-site event in summer 2020, the workshop was moved to an online format later in the year. After this second TC1 workshop, a post-event survey was circulated among the participants. We collected 20 responses from 36 participants, which is a good response rate. The questions covered the topics discussed in the workshop, and the organisation of the agenda and discussions. Questions and publishable responses can be found in Annex A. Overall, the session on "State of the art in CNS/ATM security and future perspectives" received 'very relevant/top priority' ratings by 73% of respondents. The rating of the session on "Research for future secure CNS/ATM systems" received mixed ratings - from not relevant to very relevant. Our interpretation of these results is that, while the first block of presentations was a high level overview of the CNS/ATM security challenges, the second block was much more technical/academic and detailed, focused on a particular topic linked to the project scope. These type of presentation are more difficult to follow by a non-experts and probably only relevant for those working on the same field. Indeed, the TC1 workshops (and therefore outputs) are determined in considerable part by the:

a) composition of the Engage CF projects and PhDs that we are supporting, by design and intention;
b) type of audience we attract (different from the parallel Scientific Committee workshops, which has more support from the SJU, for example);
c) expertise of the organisers (Innaxis and Westminster are not experts); Engage delivered the best outputs it could and invested high commitment within the resources of (a) and (b).

This TC topic continues to be of high interest. The increasing levels of digitalisation and data services lead to even higher needs of secure systems that protect information and data sharing in ATM. The revolution in the sector in the coming years, supported by several strategic agendas and institutional roadmaps, makes the TC1 challenge a priority for the sector. This is still rather new in the mainstream ATM domain, however, whilst its importance grows with new developments such as virtual centres, UTM, etc. It is likely that cybersecurity matters will become more ubiquitous in ATM and these matters will become even more important as cybersecurity is often tightly linked with the domain of safety in aviation. If the SJU would like to help Engage to shape the objectives of the final TC1 workshop, Engage would be more than happy to support that, whilst it:

a) still needs to include all the Engage CF projects and PhDs (this aligns with the Engage backbone planning and continuity);
b) would like to include the active participants (still around 60 by the final workshop of the series) from the corresponding Scientific Committee workshops;
c) would like to be informed by the latest recommendations paper of the SC (around May/June 2021) on the final direction of the TC1 workshop.

Options for future consideration include targeted 'training', or 'building communities', for example, which both fit the remit of Engage, and our role in supporting the SESAR Digital Academy.

4.1.2 TC2

The second TC2 workshop was attended by 37 participants, including many Engage beneficiaries. Engage PhD students and leaders of the Engage catalyst fund projects related to data-driven trajectory prediction presented their research. Not surprisingly, the projects and PhDs had matured considerably in comparison to the first workshop in Casteldefells which took place roughly one year earlier.

Two key observations arise concerning the first and second workshops:

1. A significant share of the research presented in the workshop is built on machine learning techniques, such as reinforcement learning. Whilst it is not totally surprising that a number of data-driven approaches are using such techniques, the dominance of machine learning is still noteworthy – and in line with observations from conferences, including the SESAR Innovation Days where submissions dealing with machine learning approaches have increased significantly.
2. Entirely unrelated to the first point, Engage researchers are given a variety of opportunities to present their research (most had submitted papers and/or posters to the SIDs) so that 'yet another presentation on the same project' doesn't seem to the best use of time in the workshop. Apart from informing about the approach and results of the different PhDs and CF projects, a main objective of TC workshops is to identify synergies and common approaches and problems. Future workshops should perhaps reflect this in the agenda and shorten presentation slots in favour of sufficient time for discussion.

The third TC2 workshop will take place on 25th January 2021. Whilst the catalyst fund projects presented at the first and second workshop have been completed, the PhDs are still ongoing and will be presented; likewise the second wave of Engage CF projects which were awarded following the second call for catalyst fund projects will be presented; we look forward to seeing the interactions and synergies between the now advanced PhDs and the new CF projects.

4.1.3 TC3

There is a need to include good weather information in tactical air traffic control, which currently does not exist (an integrated pre-tactical EU-wide picture is being developed). There is a need for an EU-wide MET picture in both the pre-tactical and tactical phases.

There is a great need for closer collaboration between forecasters and controllers in order to develop products that are easy to interpret by the controllers in terms of the impact weather will have on the airspace under their control (and neighbouring areas), e.g. 'red'/'purple' areas. Note that a 'medium' risk is still a risk when forecasting. Furthermore, further training on the meaning of probabilistic forecasts for pilots and controllers is needed. As the state-of-the-art in the modelling is moving towards the probabilistic approach, there is a need to transfer this knowledge to the end-users (controllers and pilots).

There is thus a need for an EU-wide, one-stop repository of MET data and to find a way of achieving it – both from the data harmonisation point of view and the funding for the archiving of data. The Engage wiki could form a useful basis for developing such an open and collaborative approach and platform.

4.1.4 TC4

Notwithstanding their high quality, this thematic challenge has had the fewest catalyst fund projects awarded, with one in each wave ('Exploring future UDPP concepts through computational behavioural economics', Nommon Solutions and Technologies (Spain); wave 1, closed) and 'Role of markets in AAS deployment (RoMiAD)', Think Research (UK); wave 2, due to complete in May 2021). Whilst TC4 embraces a wide range of potential research domains under the title 'novel and more effective allocation markets in ATM', with a broad spectrum of ideas for potential further exploration discussed and enumerated in Section 3.5, this TC runs the greatest risk of becoming uncoupled from some of the corresponding ER4 latest research activity, due to the combined effect of the lower number of CF projects involved and the particularly wide remit of the challenge. This is notwithstanding the good participation of the Engage partners, CF project partners and other invited participants at the previous workshops.

The latest workshop for this challenge was held in July 2020 (see Table 1 and Annex B) and the workshop planned for May 2021 (TBC), to coincide with the conclusion of the RoMiAD project (see Table 1 and Table 7) is anticipated to be the last formal TC4 workshop in Engage. Particularly mindful of the lower number of Engage activities associated with TC4, we should therefore consider how to best design the format and content of this workshop to maximise its value, for example in feeding forward ideas for new research areas in SESAR 3, and embracing a (more) systematic inclusion of ER4 projects. In the SESAR ER4 Call (Technical Specification of SESAR 2020 Exploratory Research Call H2020-SESAR-2019-2 (ER4), 25 April 2019), under Work Area 1 ("ATM Excellent Science & Outreach"; starting at pre-TRL 1), which is also described as 'fundamental scientific research', Sub Work Area 1.4 (Performance, Economics, Legal and Regulation) included the topic: "**SESAR-ER4-08-2019: Behavioural Economics in ATM**", the scope of which was fed in part by earlier outputs from TC4 itself:

The application of economic models supports well targeted policy making. However, current economic models applied in ATM are often normative, thus making a number of assumptions about agent rationality that have been demonstrated not to work in practice in several cases. This is because real decision are often not fully rational. An assessment of novel ATM concepts using behavioural economics in ATM at an early design stage could help to predict the actual behaviour of ATM stakeholders and inform decisions about the specific design of the concepts and policy decision making related to their introduction. [...] Proposals and their research activities may investigate the application of behavioural economics to improve economic models in ATM by integrating an improved prediction of actual stakeholder behaviour. These activities should provide insights into how to incentivise desirable behavioural change and enable better decisions though incentives, policies, etc.

[*ibid*.]

As a result, the project BEACON was awarded.

In Work Area 2 ("ATM Application-Oriented Research"; starting at TRL 1), Sub Work Area 2.2 (Optimised ATM Network Management) specified:

The optimised ATM network management theme will include research activities in the areas of Digitalisation of the ATM Network (including network management operations and improved involvement of the Airline Operation Centre), innovations in network management (like innovative technics and models for uncertainty management and innovative route charging schemes) and fully dynamic airspace.

[*ibid*.]

As a result, the following projects were awarded:

- ECHO
- ISOBAR
- START
- CADENZA
- SlotMachine

Subject to further review of which of the foregoing projects to include in the TC4 workshop currently planned for May 2021 (TBC), the Engage consortium proposes to include BEACON, CADENZA and SlotMachine, capturing the main on-going activities in ER4 related to TC4, in addition to the RoMiAD (catalyst fund) project. This could represent a strong participant base, by pooling the respective partners and associated interested parties (such as, but not limited to, Advisory Board members).

However, as flagged above under TC2, the workshop should shorten presentation slots in favour of sufficient time for discussion, in particular for identifying future research directions. An open question here is the breadth of scope of such a workshop, e.g. Sub Work Area 1.4 in the SESAR ER4 Call (*ibid*.) is very broad as "Performance, Economics, Legal and Regulation", whereas the topic SESAR-ER4-08-2019 ("Behavioural Economics in ATM") may be too narrow, and is not best aligned with the remit of the RoMiAD project, which should form a core part of the workshop.

The wider roll-out of this approach (reviewed scoping, inclusion of ER4, targeted objectives feeding SESAR 3) is discussed further in Section 5.1.

4.2 Technical workshop lessons

There is a need for different data sets and data processing algorithms if ATM research in Europe is to progress. Some of the data sets can be obtained relatively easily, such as trajectory data available through EUROCONTROL's R&D archive (similar to DDR2 data), or ADS-B trajectories from the OpenSky network. For other data sets, such as schedules, passenger itineraries or fares, the projects need to set aside budget to be able to acquire them. Meteorological data in Europe is fragmented in a sense that a central repository of different aviation-related forecasts and observations does not exist. The aviation MET forecasts and observations can be accessed through the NOAA website. Other ensemble forecasts can be accessed through the EMCWF. There is also a myriad of different Earth atmosphere observation data sets available through ESA.

Obtaining the data is just a first step in any research as even the cleanest data has to be prepared for the purpose of the specific research project. There are some techniques/algorithms that various research institutions developed over the years. ATM research would benefit from an exchange of experiences in this area, which the technical workshops with the Engage KTN students demonstrated.

The Engage wiki data repository could provide a useful environment for such data (and code) sharing, especially for common (clean) data sets to promote cross-project comparison and calibration/validation (which is currently lacking).

4.3 General lessons learned

4.3.1 Post-event surveys

The latest TC1 workshop (10NOV2020) added a post-event survey. The response rate was quite high and good feedback was received. Future workshops could adopt a similar approach, as such surveys can help in the following:

1. obtaining individual participant's inputs on the workshop conclusions, helping to elaborate them;
2. receiving feedback on the quality of the agenda and the balance between the operational and research issues presented and discussed;
3. capturing further ideas not raised during the workshop (e.g. regarding future research).

4.3.2 Workshop length

The workshops reported on in this deliverable were mostly held during one working day, which was preferred by participants to a longer event, in all planning consultations made. The last TC1 workshop lasted half a day. The next TC2 and TC3 workshops will be held in January 2021 and have a full day schedule. It is to be seen which of the two settings (half day or a full day) is more convenient in the virtual setting, also taking into account the goals of the workshops and the density of virtual events across the period. It is clear that a balance is to be struck between good content coverage, and allowing sufficient time and energy (minimising screen fatigue) for a useful discussion at the end of the workshop, without which the value thereof is greatly diminished. Feedback on the January 2021 workshops will also help to inform future planning in this respect.

5 Workshop planning for 2021; next steps

5.1 Final thematic challenge workshops – schedule and design

As mentioned in Section 2, the third edition of the TC2 and TC3 workshops were moved to January 2021. This was due primarily to Covid-19 impacts as many events had been moved to virtual environments. To avoid overlap with other initiatives and participant overload, the workshops were postponed to a freer month:

1. TC2, 25 January 2021.
2. TC3, 27 January 2021.

The final round of TC workshops is expected to be scheduled after the second wave of catalyst funding projects are scheduled to close, i.e. from July 2021 (see Table 7). It may make sense to co-locate one of the workshops with the Engage 2021 summer school. This co-location would depend on the maturing content of the summer school (itself aiming at addressing how some of the PhD content might be taken up by industry), how this aligned with one of TC1-3 (if at all), and to avoid a clash with ER4 intermediate review meetings (likely to clash more heavily with TC3 participants, it would seem). One potential advantage would be attracting a shared audience across the traditional summer school participation (usually more academic) and the selected TC (typically more from industry). Note that the summer school might be a hybrid physical (University of Trieste) and virtual event, or purely virtual. A provisional timetable is presented in Table 8.

Table 7. Engage wave 2 catalyst fund project dates

ID	Project title	TC	Start date	IPR window opens	End date
204	Proof-of-concept: practical, flexible, affordable pentesting platform for ATM/avionics cybersecurity	1	01JUL20	01JAN21	30JUN21
208	Safe drone flight - assuring telemetry data integrity in U-Space scenarios	1	03JUL20	03JAN21	02JUL21
209	Flight centric ATC with airstreams (‘FC2A’)	Open (2)	01JUL20	01JAN21	30JUN21
212	Meteo Sensors In the Sky (‘METSIS’)	3	01JUL20	01JAN21	30JUN21
214	Probabilistic information Integration in Uncertain data processing for Trajectory Prediction (‘PIU4TP’)	2	01JUL20	01JAN21	30JUN21
215	Collaborative cyber security management framework	1	01JUN20	01DEC20	31MAY21
218	Role of Markets in AAS deployment (‘RoMiAD’)	4	01JUN20	01DEC20	31MAY21
220	Weather impact prediction for ATM (‘WIPA’)	3	01JUL20	01JAN21	30JUN21

Table 8. Engage final thematic challenge workshop and summer school schedule (provisional)

Thematic challenge / event	Date
Engage summer school (University of Trieste / hybrid / virtual event)	30 August – 03 September 2021
TC1 - Vulnerabilities and global security of the CNS/ATM system	01 July 2021 – 15-September 2021
TC2 - Data-driven trajectory prediction	
TC3 - Efficient provision and use of meteorological information in ATM	
TC4 - Novel and more effective allocation markets in ATM	May 2021

For each TC workshop in Section 4, ***generically, these workshops should***:

1. ensure that the thematic challenge context is appropriately updated to reflect the latest progress in ER4 (and, preferably, the IR programme) and that the workshop is thus able to support the identification of new research areas to be explored in SESAR 3 as a key output (this could be partially managed in advance through the use of a questionnaire to participants to inform the corresponding discussion in the workshop);
2. be mindful of the intense programme of virtual events and try to avoid scheduling conflicts (even two large events (such as a summer school and full conference) over consecutive weeks is not attractive for participants);
3. shorten presentation slots in favour of sufficient time for targeted discussion;
4. further to (3), strike a balance between good content coverage, and allowing sufficient time and energy (minimising screen fatigue) for a useful discussion at the end of the workshop, without which the value thereof is greatly diminished; recent (January 2021) feedback will also help to inform future planning in this respect;
5. be followed by brief surveys to capture further feedback on future research initiatives and to inform lessons learned regarding workshop implementation.

Highlighting some of the key points of the detailed preceding discussions, ***additionally and specifically, the workshops should***:

- TC1 (Vulnerabilities and global security of the CNS/ATM system) – future planning should build on the corresponding Scientific Committee workshops and be informed by its latest recommendations, taking informed advice from the SJU and Engage partner EASA to shape the objectives of the workshop, possibly mindful of opportunities of synergies regarding supporting the SESAR Digital Academy;
- TC2 (Data-driven trajectory prediction) – much of this research is built on machine learning techniques, such as reinforcement learning, and this could become a broader focus of the workshop, coupled with AI and linked to automation; applied examples from Clean Sky 2 projects could usefully be added;
- TC3 (Efficient provision and use of meteorological information in ATM) – the interests raised within this TC produced consortia of six new ER4 projects in the MET/ENV area; TC3 thus achieved its original goal, of proposing and addressing topics less covered within the SESAR 2020 programme: a key next step would be to further channel the collaboration to inform and

shape the needs and performance inputs for the Green Aviation roadmap of the European Partnership for integrated ATM;

- TC4 (Novel and more effective allocation markets in ATM) – an open question here is the breadth of scope the workshop, with "Performance, Economics, Legal and Regulation" (Sub Work Area 1.4, SESAR ER4 Call) being too wide and the specific topic SESAR-ER4-08-2019 ("Behavioural Economics in ATM") may be too narrow; the remit of the Engage CF project, RoMiAD, and selected, compatible ER4 projects should drive a coherent and realistic scope.

5.2 Other workshop activities

Engage remains ready to potentially support other workshop activities in 2021, which might include:

- an ER4 intermodal workshop, taking advantage of the 'European Year of Rail'[10] in 2021, and collaborating with the wider railways research community and partners, in particular Shift2Rail;
- further technical workshops for Engage PhDs, if required;
- a dedicated workshop on promotion of the Engage wiki, and attracting contributions from the research community to the ATM concepts roadmap (this also feeds D3.6, indicated below);
- the meteorological technology expo (aviation meteorology virtual conference);
- supporting workshops organised by the SESAR Digital Academy Task Force of the SESAR Scientific Committee.

5.3 Next steps – key future deliverables

As the Engage KTN is coming to an end in 2021, it is important to capture the achievements of the thematic challenges, the associated catalyst fund projects (which will be closed by mid-2021) and also drawing on the PhD progress thus far, where appropriate, in particular identifying opportunities for future research, plus barriers and enablers regarding transfer to higher TRLs. The next version of *this* deliverable, i.e. D2.6 (*Annual combined thematic workshops progress report (series 2)*), will be D2.7 (*Annual combined thematic workshops progress report (series 3)*), as shown below, due in September 2021.

Final, joint reporting on the catalyst fund projects, *per se*, with their outcomes and recommendations (across waves 1 and 2), will feature within the much broader remit of D3.6, as shown below, which is scheduled for October 2021, and which will be partially fed by D2.7.

D2.7 *Annual combined thematic workshops progress report (series 3)* **(30SEP21)**

D3.6 *Opportunities for innovative ATM research* **(31OCT21)**

[10] The official launch of the European Year of Rail will take place online on 29 March 2021.

6 Acronyms

Acronym	Definition
4D	four dimensional
AI	artificial intelligence
ABM	agent-based modelling
ACI	Airports Council International
ADS-B	Automatic Dependent Surveillance–Broadcast
ANSP	air navigation service provider
ATFCM	air traffic flow control management
ATFM	air traffic flow management
ATC	air traffic control
ATM	air traffic management
AU	airspace user
AUA	air traffic control unit airspace
BE	behavioural economics
BPBS	best-performing best-served
CAPE	convective available potential energy
CASA	computer-assisted slot allocation
CANSO	Civil Air Navigation Services Organisation
CD&R	conflict detection and resolution
CF	catalyst funding
CIN	convective inhibition
CNS	communication navigation surveillance
COTS	commercial-of-the-shelf
CPLP	centralized peak-load pricing
DCB	demand capacity balancing
DFS	Deutsche Flugsicherung
DSNA	Direction des Services de la Navigation Aérienne
EASA	European Union Aviation Safety Agency
EATMA	European ATM architecture
EFB	electronic flight bag
EMCWF	European Centre for Medium-Range Weather Forecasts
ENV	environmental

ER	exploratory research
ESA	European Space Agency
ESFP	Extended-SFP
ESS	enhanced slot swapping
EU	European Union
EUMETNET	grouping of 31 European National Meteorological Services
EUROCAE	Non-profit organisation dealing exclusively with aviation standardisation, for both airborne and ground systems and equipment
FDIA	false data injection attack
FPFS	first-planned, first-served
GNSS	Global Navigation Satellite System
HALE	high-altitude long endurance vehicles
HITL	human-in-the-loop
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
ICB	Industry Consultation Body
IPCC	Intergovernmental Panel on Climate Change
IR	industrial research
IT	information technology
KNMI	Koninklijk Nederlands Meteorologisch Instituut
KTN	knowledge transfer network
KPA	key performance area
KPI	key performance indicator
LIDAR	light detection and ranging
LI	lifted index
MET	meteorology in aviation
METAR	Meteorological Aviation Routine Weather Report
ML	machine learning
MTCD	medium-term conflict detection
MUAC	Maastricht Upper Area Control Centre
NM	network manager
NATS	National Air Traffic Services
NOAA	National Oceanic and Atmospheric Administration
NWP	numerical weather prediction
pax	passengers

R&D	research and development
RDT	rapidly developing thunderstorms
SDI	supercell detection index
SFP	Selective Flight Protection
SJU	SESAR Joint Undertaking
SRH	storm relative helicity
STCA	short-term conflict alerts
SWIM	system wide information management
TBO	trajectory-based operations
TC	thematic challenge
TCAS	traffic collision avoidance system
TMA	terminal manoeuvring area
TP	trajectory prediction
TPI	traffic prediction improvements
TRL	technology readiness level
UDPP	user driven prioritisation process
UTM	Unmanned Aircraft System (UAS) Traffic Management

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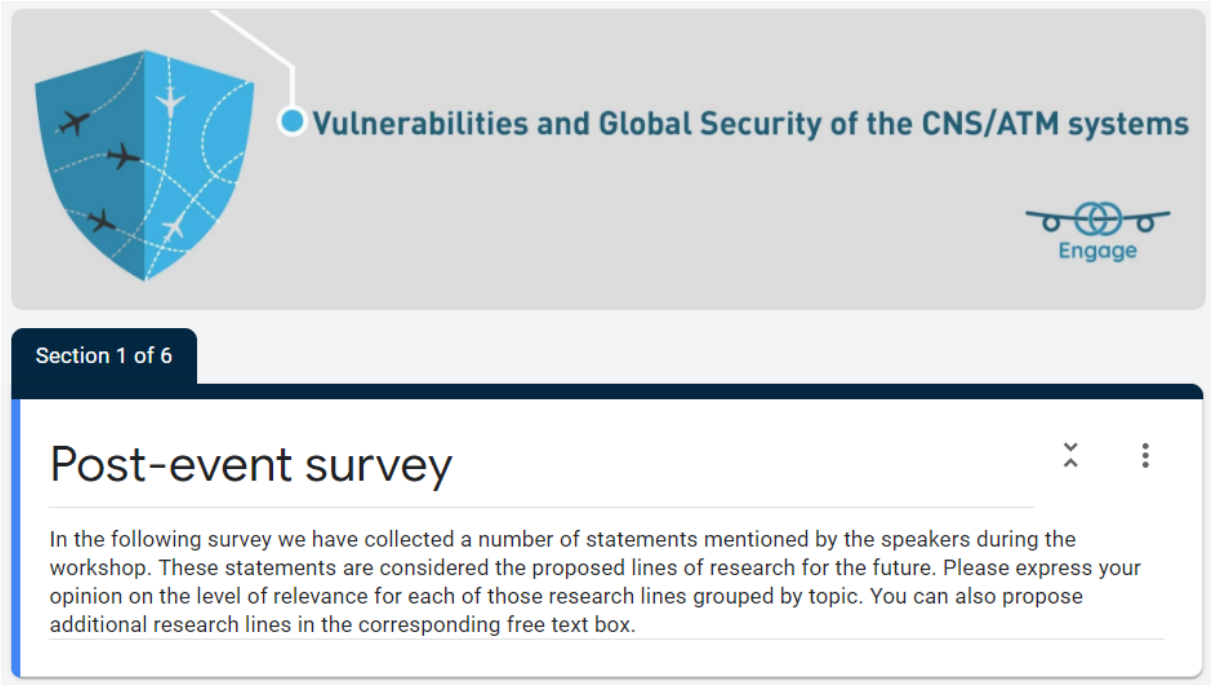
Annex A TC1.2 Post-event survey

The responses to the survey have been edited to remove data relating to individual presenters, in order to conform with GDPR requirements.

A1. Survey questions



Topic 1: Information sharing infrastructure and performance monitoring.

Please rate the statements below.

1= Not relevant at all

2 = Slightly relevant

3 = Relevant

4 = Very relevant / Top priority

Regulations and policies are needed in order to overcome national and organisational sensitivities and confidentialities and develop an information sharing trust framework in Europe. *

1	2	3	4
○	○	○	○

The new model for ATS data proposed by EUROCONTROL, together with the digitalisation of the industry, opens new data markets in which current levels of security need to be maintained. This requires further regulation and certification. *

1	2	3	4
○	○	○	○

There is a need for better metrics & KPIs to measure the cyber-resilience of the system and to help monitor performance standards. The development of these metrics/KPIs should be the responsibility of ICAO or EASA. (Or another organisation? Please specify in the comment box below.) *

1	2	3	4
○	○	○	○

Please add any comment or additional statements related to this block:

Long-answer text

Topic 2: Automation and AI/ML technologies in the aviation cybersecurity landscape

Please rate the statements below.

1= Not relevant at all

2 = Slightly relevant

3 = Relevant

4 = Very relevant / Top priority

AI and ML are at early stages of development within the ATM industry and therefore further R&D effort is needed in order to understand how these technologies can be safely deployed and certified. *

1	2	3	4
○	○	○	○

These new technologies pose uncertain threats. R&D efforts are needed to understand to what extent cybersecurity can be 'automated' and managed with AI/ML (e.g discovering vulnerabilities, speeding up responses to attacks, or autonomously patching). *

1	2	3	4
○	○	○	○

Currently, there is a lack of required training and understanding of these new technologies by human operators, thus posing possible vulnerabilities. *

1	2	3	4
○	○	○	○

Please add any comment or additional statements related to this block:

Long-answer text

Topic 3: Drones and UTM security.

Please rate the statements below.

1= Not relevant at all

2 = Slightly relevant

3 = Relevant

4 = Very relevant / Top priority

The integrity of drone telemetry and information shared is key for safe and secure operations. R&D of efficient and effective tracking systems and cyber-secure data transfer systems is needed. *

1	2	3	4
○	○	○	○

New UTM regulatory actions are needed in order to ensure the required levels of cybersecurity for drone operations. *

1 2 3 4

The introduction of High-Altitude Long Endurance (HALE) operations (above 50 000ft) pose important operational and security risks for aircraft operating below. *

1 2 3 4

The development of incident and accident analysis, and investigation frameworks, is needed in order to ensure adequate safety and security levels of drone operations during exceptional conditions (e.g. accidents, battery failures). *

1 2 3 4

Please add any comment or additional statements related to this block:

Long-answer text

Topic 4: Other research areas.

Please rate the statements below.

1= Not relevant at all

2 = Slightly relevant

3 = Relevant

4 = Very relevant / Top priority

A self-strengthening aviation system through 'built-in security' iterations to face new threats in a more automated way ('anti-fragility') is needed. *

1	2	3	4
○	○	○	○

Protection of the electromagnetic spectrum (e.g. spoofing and jamming) should remain high on the research agenda. *

1	2	3	4
○	○	○	○

The air transport / ATM industry should take advantage of Commercial Off-The-Shelf (COTS) solutions as well as looking at other sectors (e.g. banking, nuclear). *

1	2	3	4
○	○	○	○

Please add any comment or additional statements related to this block:

Long-answer text

Event feedback

Description (optional)

Did you finally attend the event? *

- Yes
- No

Only answer the following questions if you did attend the event!

Description (optional)

Please rate the content of session 1: Ruben Flohr (SESAR JU), Robert Westerberg (NATS), Davide Martini (EASA).

	1	2	3	4	
Not useful	○	○	○	○	Very useful

Please rate the content of session 2: Matthias Schäfer (SeRo Systems and OpenSky Network), Yijun Yu (The Open University), Kanaan Abdo, Fun Hu, Muhammad Ali (SINAPSE project)

	1	2	3	4	
Not useful	○	○	○	○	Very useful

Please rate how useful you found the two Q&A sessions held in the event.

	1	2	3	4	
Not useful	○	○	○	○	Very useful

Please add any comment or suggestion to be taken into account in future workshops

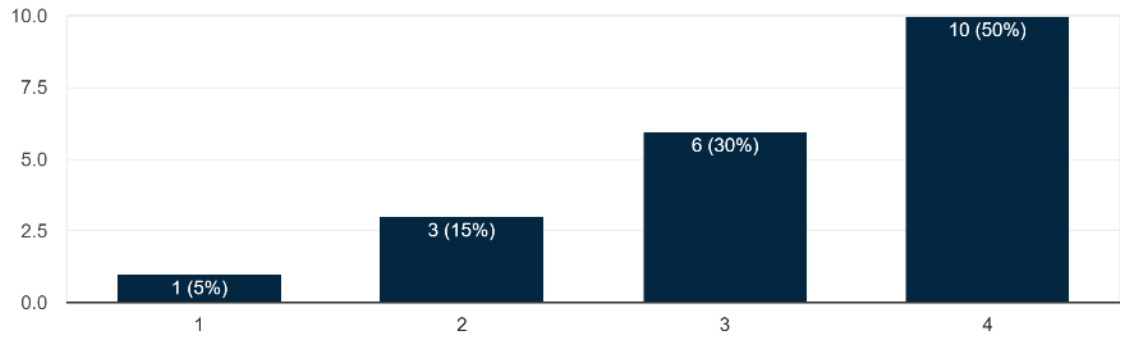
Long-answer text

A2. Responses

Topic 1

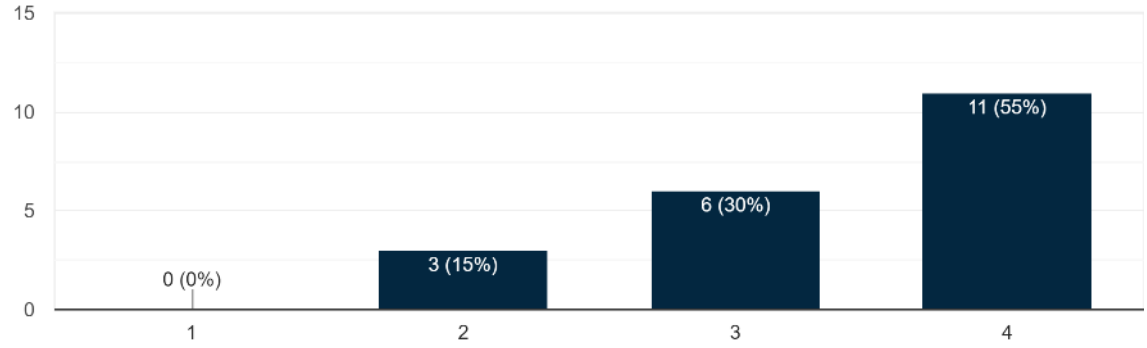
Regulations and policies are needed in order to overcome national and organisational sensitivities and confidentialities and develop an information sharing trust framework in Europe.

20 responses



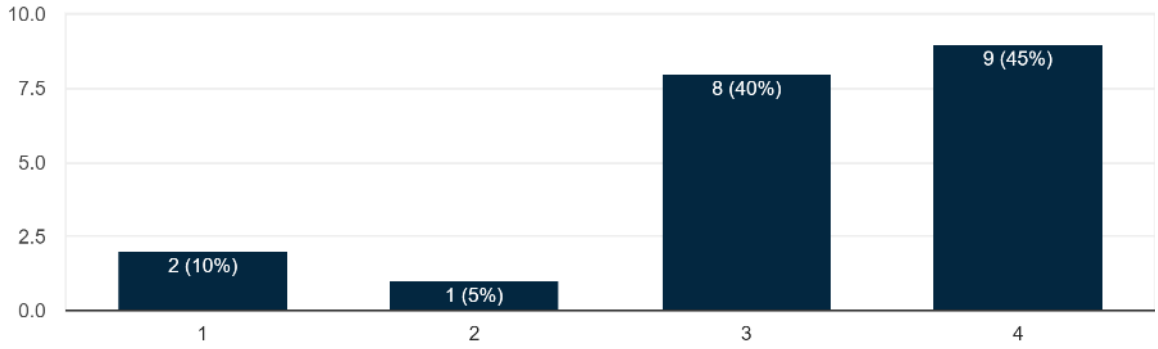
The new model for ATS data proposed by EUROCONTROL, together with the digitalisation of the industry, opens new data markets in which current I...This requires further regulation and certification.

20 responses



There is a need for better metrics & KPIs to measure the cyber-resilience of the system and to help monitor performance standards. The development ...tion? Please specify in the comment box below.)

20 responses



Please add any comment or additional statements related to this block:

4 responses

metrics and KPIs should be the responsibility of Aviation Authority

Icao and EASA

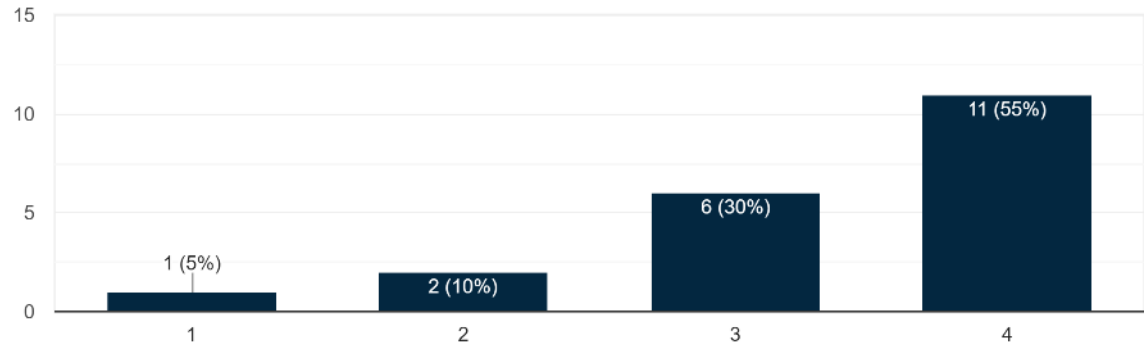
I would be happy to get involved in any further collaborations with the participants in the workshop.

Whilst global metrics will need to be through ICAO we should recognise that ICAO processes are not dynamic enough for what we need. Would suggest that EASA lead (recognising the need to engage with ANSPs in States not covered by EASA) and feed up into ICAO to help drive the global picture.

Topic 2

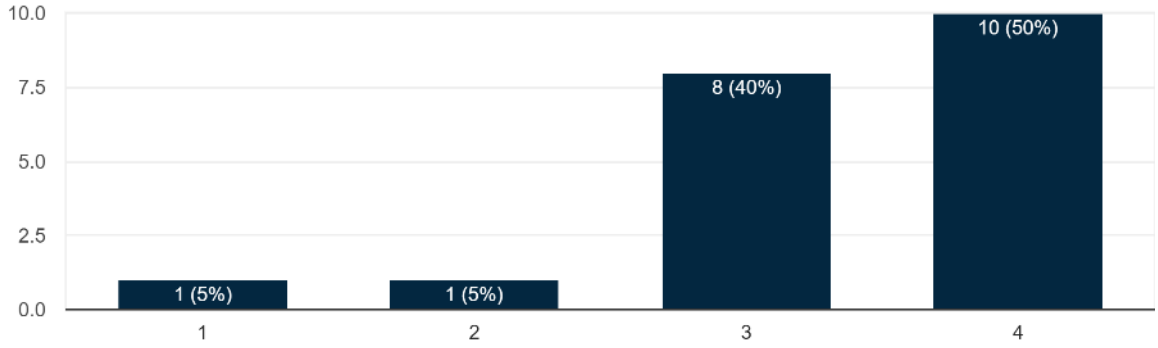
AI and ML are at early stages of development within the ATM industry and therefore further R&D effort is needed in order to understand how these technologies can be safely deployed and certified.

20 responses



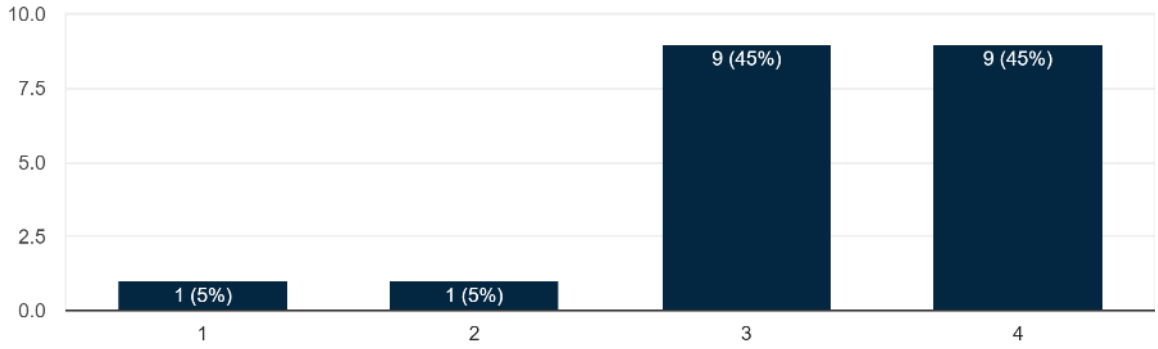
These new technologies pose uncertain threats. R&D efforts are needed to understand to what extent cybersecurity can be 'automated' and mana...responses to attacks, or autonomously patching).

20 responses



Currently, there is a lack of required training and understanding of these new technologies by human operators, thus posing possible vulnerabilities.

20 responses



Please add any comment or additional statements related to this block:

3 responses

experts in ATM domains should previously be well trainned before implementation of IA/ML

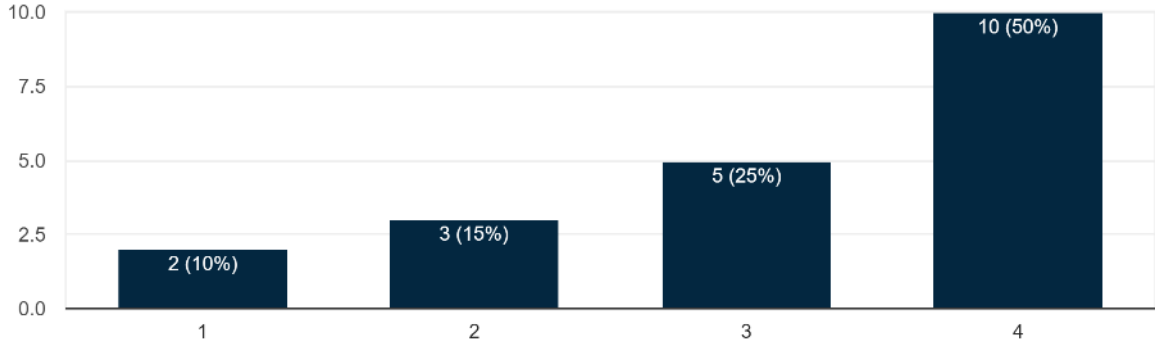
Neither ML and AI aren't new nor is it ML/AI in the context of cybersecurity. Don't invent the wheel new.

AI for Aviation is definitely worthwhile to explore, especially many of the forensic investigation decisions depend on the evidence made of the data one can collect from the incidents.

Topic 3

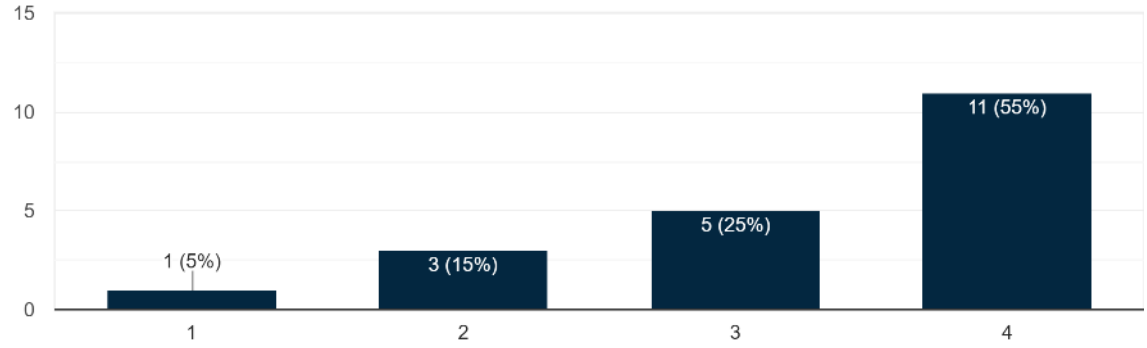
The integrity of drone telemetry and information shared is key for safe and secure operations. R&D of efficient and effective tracking systems and cyber-secure data transfer systems is needed.

20 responses



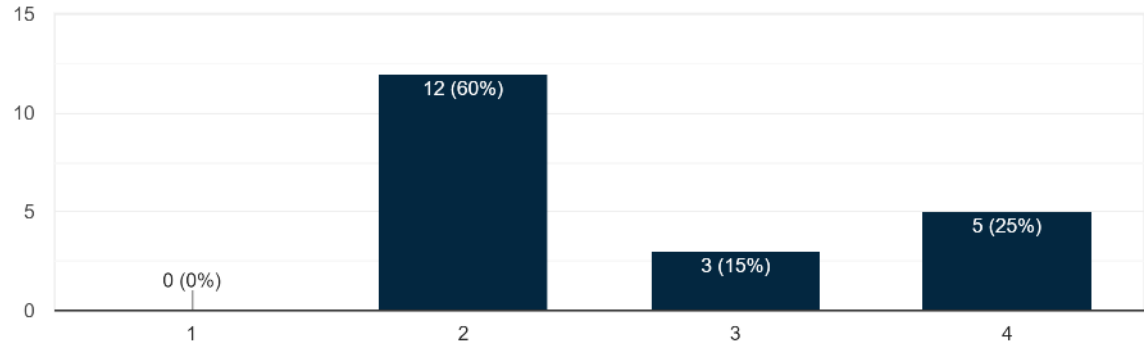
New UTM regulatory actions are needed in order to ensure the required levels of cybersecurity for drone operations.

20 responses



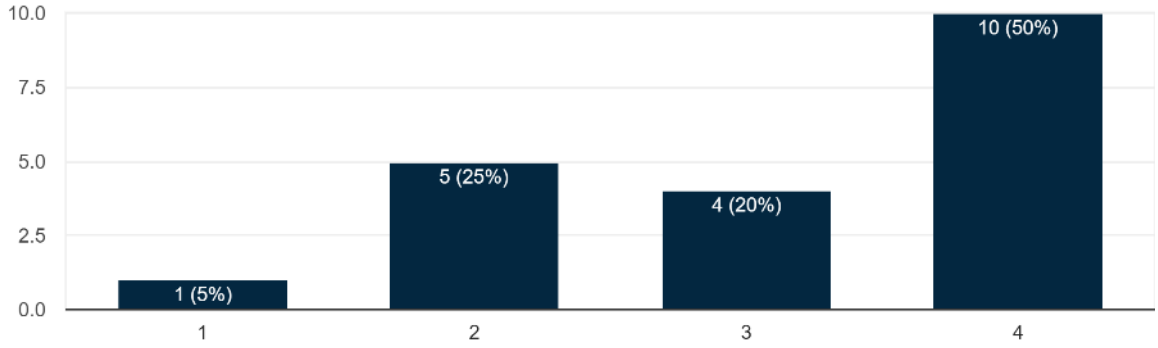
The introduction of High-Altitude Long Endurance (HALE) operations (above 50 000ft) pose important operational and security risks for aircraft operating below.

20 responses



The development of incident and accident analysis, and investigation frameworks, is needed in order to ensure adequate safety and security levels ...ional conditions (e.g. accidents, battery failures).

20 responses



Please add any comment or additional statements related to this block:

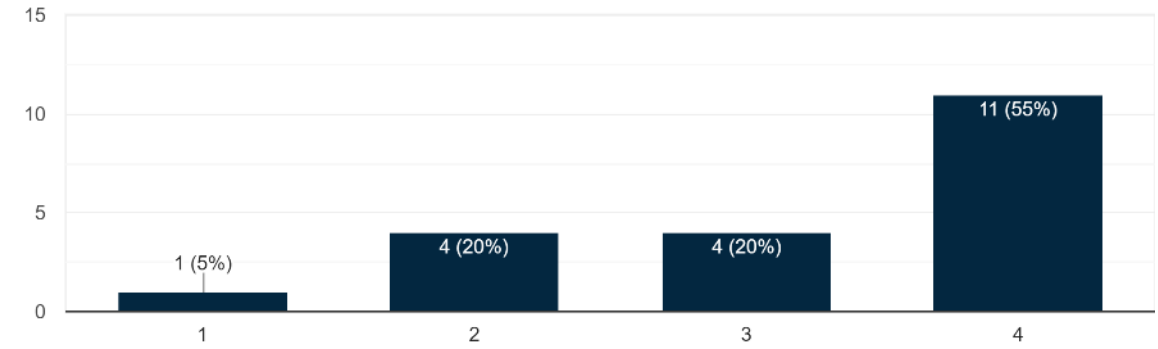
1 response

This is really my research area and I would welcome any collaboration on this theme.

Topic 4

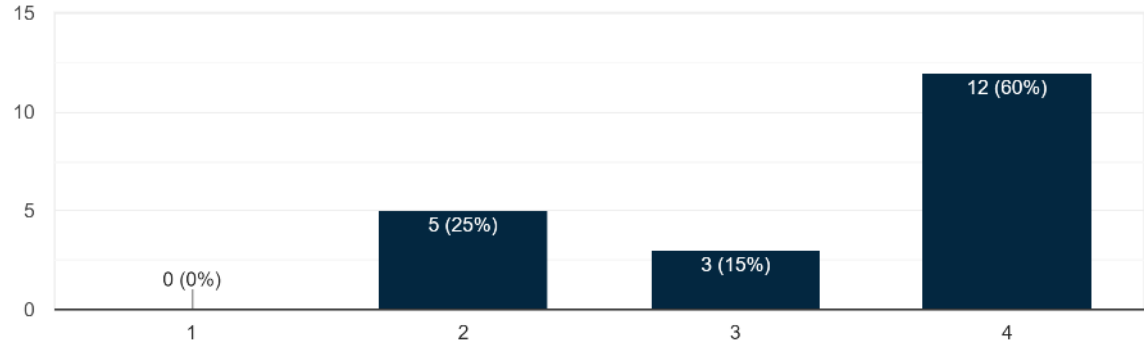
A self-strengthening aviation system through 'built-in security' iterations to face new threats in a more automated way ('anti-fragility') is needed.

20 responses



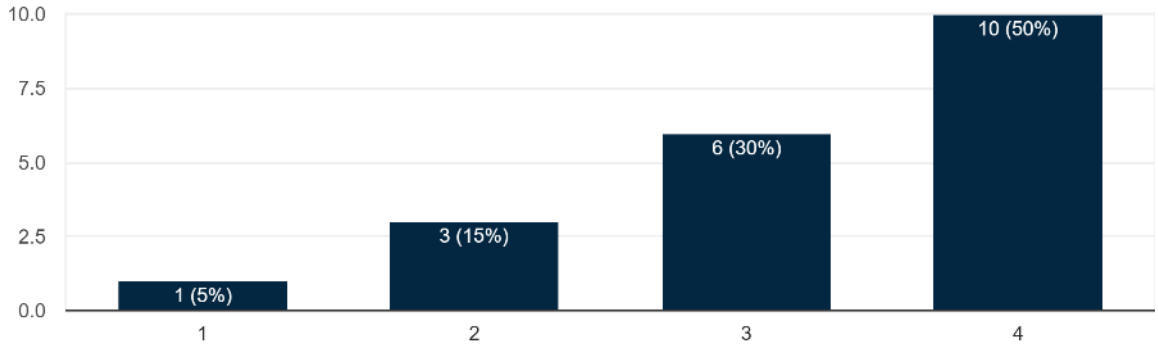
Protection of the electromagnetic spectrum (e.g. spoofing and jamming) should remain high on the research agenda.

20 responses



The air transport / ATM industry should take advantage of Commercial Off-The-Shelf (COTS) solutions as well as looking at other sectors (e.g. banking, nuclear).

20 responses



Please add any comment or additional statements related to this block:

2 responses

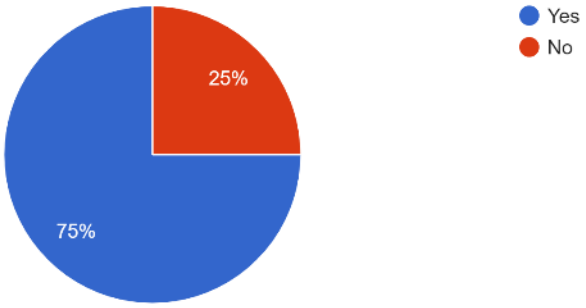
COTS COTS COTS.

How and spoofing/jamming be detected from the attackers is very challenging but interesting question to me.

Topic 5

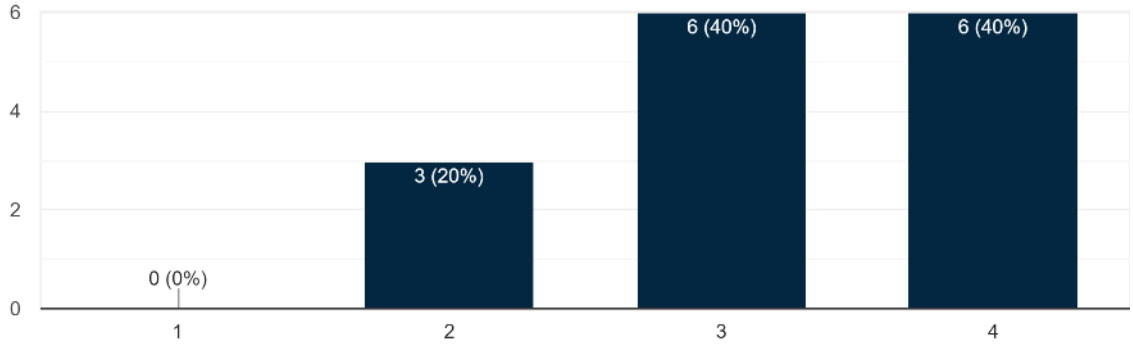
Did you finally attend the event?

20 responses



Please rate how useful you found the two Q&A sessions held in the event.

15 responses



Please add any comment or suggestion to be taken into account in future workshops

1 response

I got very useful feedback and questions from the panel discussions, and identified some potential collaborators (need to talk to them offline :-)

Annex B Nommon workshop – 27JUL20

This material exemplifies independent workshops organised by the catalyst fund projects. A range of participants took part (including EUROCONTROL and SWISS). Fuller reporting was taken forward to the catalyst fund project's final reporting to Engage, and is captured in a dedicated deliverable.

B1. Workshop invitation

Exploring Future UDPP Concepts through Computational Behavioural Economics

"Exploring future UDPP concepts through computational behavioural economics" is a research project funded under the first catalyst funding call of SESAR's Engage Knowledge Transfer Network (https://engagektn.com/), within Thematic Challenge 4 'Novel and more effective allocation markets in ATM'. The goal of the project is to develop new modelling approaches enabling a rigorous and comprehensive study of advanced UDPP mechanisms. To this end, the project adopts the paradigm of agent-based computational economics, as a particularly suitable framework for the representation of features that are not properly captured by classical approaches. The project started on 15th June 2019 and now has reached its final stage. The project has produced 4 main outcomes:

1. An **assessment framework** for the comprehensive evaluation of the impact of UDPP mechanisms on network performance and on ATM stakeholders.
2. A detailed **review of the tactical slot and trajectory allocation mechanisms** proposed in the literature, identifying the ones that appear as most promising to improve UDPP.
3. A**n agent-based model** allowing the evaluation of different UDPP mechanisms.
4. A set of **simulation experiments**, considering different AUs' behavioural assumptions, in order to conduct a systematic assessment and comparison of the identified UDPP mechanisms.

This workshop is conceived as a hands-on working session with a reduced number of participants representing a variety of ATM stakeholders, and has a threefold purpose:

1. Present the model developed by the project and collect feedback on the modelling assumptions.
2. Present the main project results and gather experts' inputs on the interpretation of these results.
3. Discuss future research lines.

Background material

A presentation summarising the main project results will be distributed before the workshop

Programme

Welcome and introduction

Engage Project presentation

Guided discussion

- *Are the model assumptions and limitations reasonable for the different stakeholders? What precautions should be observed when interpreting the results?*
- What can we learn from the simulation results?
- *Are we overlooking any aspect that should be included in future related projects? What should future research focus on?*

B2. Workshop summary conclusions

Exploring Future UDPP Concepts through Computational Behavioural Economics

This document consolidates the conclusions from the working session organised by the Engage Catalyst Fund Project "Exploring Future UDPP Concepts through Computational Behavioural Economics" on the 27th of July 2020. The event consisted of a general description of the project, with special emphasis on the implementation of the agent-based model, followed by an analysis and a discussion of the main results.

The main modelling assumptions were considered reasonable for the scope of the project. However, two of them sparked a more intense debate. First, the prohibition of a flight occupying an ATFM slot when this creates a demand-capacity problem in an already resolved time window was considered too rigid. This approximation is a centralised abstraction of the problem, which in real operations is often solved by the decentralised work of different Flow Management Positions (FMPs). Different approaches can be tested in order to study the sensitivity of the model results against this particular modelling assumption. Second, the cancellation policy included in the model was discussed. For the sake of simplicity, in the model only flight cancellations due to airport curfew are considered. Although this was considered an acceptable assumption, the shared opinion was that more sophisticated approaches to model flight cancellations are needed to improve future research.

The two most prominent aspects of the results presentation were the counterintuitive phenomena present in some simulations, such as the scenario with the Selective Flight Protection without the rerouting option available, and the comparison of irrational behaviours against the rational one, with special interest in the hyperbolic discounting bias. During the discussion, it was also suggested the need for the future implementation of new metrics related to delay, for example some reactionary delay indicator or simply the use of different thresholds to calculate delayed flights. Furthermore, the need for new flexibility metrics from AUs' perspective was also stated.

From all the interesting contributions, we identified several aspects to be further investigated in future related projects. First, although the results and conclusions drawn from the comparison with the scenarios including irrational behaviours are very interesting and promising, it is an initial implementation and it is recommended to continue its development in future research (e.g., in the SESAR ER4 BEACON project), by exploring more complex airline strategies and 'irrational' behaviour. Second, new improvements to the model should be aimed at increasing the simulation time frame to more than one day in order to allow the implementation of airlines' learning capabilities and adaptive behaviour. Third, it was suggested to extend this evaluation to more prioritisation mechanisms, with special interest in different types of auctions. In fact, a particular auction variation was proposed with the use of credits instead of money, in order to mitigate airlines' reluctance to using monetary flight prioritisation mechanisms. Finally, the use of a more complex representation of the European network was found essential to obtain more realistic and accurate results.

-END OF DOCUMENT-