D2.5 Annual combined thematic workshops progress report (priming wave 1)

Deliverable 2.5

Engage

Grant:	**783287**
Call:	**H2020-SESAR-2016-2**
Topic:	**SESAR-ER3-01-2016 Knowledge Transfer Network**
Consortium coordinator:	**University of Westminster**
Edition date:	**25 January 2019**
Edition:	**01.01.00**

SESAR JOINT UNDERTAKING

Authoring & Approval

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N/A		

Document History

Edition	Date	Status	Author	Justification
01.00.00	21 December 2018	Release	Engage Consortium	New document for review by the SJU
01.01.00	25 January 2019	Release	Engage Consortium	Incorporating SJU comments

Engage

THE SESAR KNOWLEDGE TRANSFER NETWORK

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

Abstract

The preparation, organisation and the conclusions from the three thematic challenge workshops held in 2018 are described. The preparation and expert consultation results are reported for the "Vulnerabilities and global security of the CNS/ATM system" challenge workshop, which is scheduled to take place in March 2019.

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Executive summary

This document reports on the organisation and results obtained from the thematic challenge workshops in 2018. The Call for thematic challenges was open on the Engage website [1] between January and March 2018, with proposals submitted via an on-line form: 54 proposals were received from 33 organisations, resulting in four chosen thematic challenges:

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.

The intended format of the thematic challenge (TC) workshops was the following: they should last one day only, be free of charge to attend and attract around 30 participants – they should have a strong emphasis on discussion regarding the maturing of the challenge, with facilitated discussion, rather than simply packing in a series of presentations. Interdisciplinarity is strongly encouraged, with limited funds to pay for such speakers' travel. These intents have been met, as documented in the following sections.

Three out of four workshops have been held to-date. The "Vulnerabilities and global security of the CNS/ATM system" workshop is postponed until March 2019, as it was not possible to organise the workshop before the publication of the first catalyst funding Call and 8th SESAR Innovation Days.

As the thematic challenges are closely linked with the catalyst funding, the goal was to organise all the workshops, and collect the conclusions before the publication of the catalyst funding Call. All the material from the workshops, such as presentations, descriptions of challenges and workshop conclusions are public and are published on the Engage website [1], with the goal to help parties interested in applying for catalyst funding.

Acknowledgement

The Engage consortium would like to sincerely thank all those who proposed and contributed to the development of these thematic challenges, whose names it was agreed to keep confidential, and especially to those who helped to support the subsequent workshops, not least the speakers who kindly also devoted their time to these discussions. Our thanks are warmly extended to all for making this first tranche of the thematic challenge development possible and, indeed we hope, such a success.

1 Introduction

1.1 Objectives of this document

This document reports on the organisation and results obtained from the thematic workshops in 2018. The timing of this delivery is intended to inform the process of the on-going definition of the ER4 Call.

1.2 Thematic challenge selection

Here we document the organisation of the thematic challenge workshops and the conclusions obtained. As a background, the thematic challenges address research topics not currently (sufficiently) addressed by SESAR, and are supported by dedicated workshops. The Call for thematic challenges was open on the Engage website [1] between January and March 2018, with proposals submitted via an on-line form. 54 proposals were received from 33 organisations, covering:

- Industry (including airspace users and ANSPs);
- Research institutes;
- Universities;
- Consultancies.

At the end of selection process (described in detail in the deliverable D3.4 [2]) four thematic challenges were chosen to pursue in the first year of the KTN (with two reserve themes):

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.

1.3 Catalyst funding link

A key feature of the Engage KTN is its focus on selecting thematic challenges that require further research efforts, but also offering paths to address them. The above listed challenges may be investigated further through, e.g.:

- Engage catalyst funding (NB. consortium members are ineligible), Call published on 15 November 2018;
- Engage PhDs/theses.

The aim of the catalyst funding is to further promote cooperation between industry and academia, between exploratory research (ER) and applied research, by funding focused projects, stimulating the transfer of exploratory research results towards ATM application-oriented research. This funding will be 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 TRLs. (In certain cases, catalyst funding may be awarded to develop more exploratory concepts, where these show particular promise and are not suitable to be addressed by a PhD or thesis.)

As the thematic challenges are closely linked with the catalyst funding, the goal was to organise all the workshops, and collect the conclusions before the publication of the catalyst funding Call. All the material from the workshops, like presentations, descriptions of challenges and workshop conclusions are public and are published on the Engage website [1], with the goal to help the parties interested in applying for catalyst funding.

2 Preparation of thematic challenge workshops

The intended format of the thematic challenge (TC) workshops was the following: they should last one day only, be free of charge to attend, and are expected to be relatively small (around 30 participants) with a strong emphasis on discussion regarding the maturing of the challenge, with facilitated discussion, rather than simply packing in a series of presentations. Interdisciplinarity is strongly encouraged, with limited funds to pay for such speakers' travel. These intents have been met and are documented in this deliverable.

As described in Section 1.2, four challenges were chosen, each having a few proposers. The Engage KTN added the organisational support to each challenge, thus helping the proposers in preparation, organisation and streamlining the resulting conclusions. Table 1 below lists the Engage partners supporting four challenges.

Table 1. Engage partners supporting challenges

Challenge no.	Thematic challenge title	Engage partners supporting *(no implied order)*
1	Vulnerabilities and global security of the CNS/ATM system	Innaxis EUROCONTROL Frequentis
2	Data-driven trajectory prediction	University of Belgrade EUROCONTROL
3	Efficient provision and use of meteorological information in ATM	University of Trieste Technical University of Delft
4	Novel and more effective allocation markets in ATM	University of Westminster University of Trieste

Engage contacted the challenge proposers to form the thematic challenge teams. Each thematic challenge team (Engage partners, proposers, and SJU members) set-up their own shared work space where three threads were addressed:

1. Finalisation of the thematic challenge:
    a. Consolidation of the abstract. Each challenge consisted of more than two proposals that dealt with the same theme, but often from different points of view. Thus, the teams worked on consolidation of the thematic challenge and consequently its abstract.
    b. Consolidation of the thematic challenge (longer) descriptions. The descriptions addressed the motivation (from an industrial and/or operational view) for each challenge, the state-of-the-art of the research and practice, and potential new research paths as well as possible barriers.
2. Workshop planning:
    a. Choice of venue and date;
    b. Choice of the workshop format (number and length of presentations, number and length of discussions);
    c. Choice of speakers;
    d. Choice of moderators for discussion sessions;
    e. Identification of the list of people / organisations / projects that should be involved in the workshop (NB: participation at the workshops is open to all interested parties, not only to the people/organisations/projects identified here.)
3. 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 and the longer description of the challenge, which were published on the Engage website, on 28 August 2018. The workshop programmes took a little longer to define and those were published on the Engage website in September.

The participation to workshops was open to all interested parties. However, as the venues had a physical limit on the number of participants (usually between 30-40 participants), the consortium set-up the registration process that is described below, and Figure 1 shows the snapshot of the registration form on the Engage KTN website [1].

To request a place:

- please visit: engagektn.com
- go to the “Contacts” page and select “Thematic challenge workshop registration”, clearly stating which workshop you wish to attend.

Three out of four workshops have been held to-date. The “Vulnerabilities and global security of the CNS/ATM system” workshop is postponed until 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.

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 Section 3.

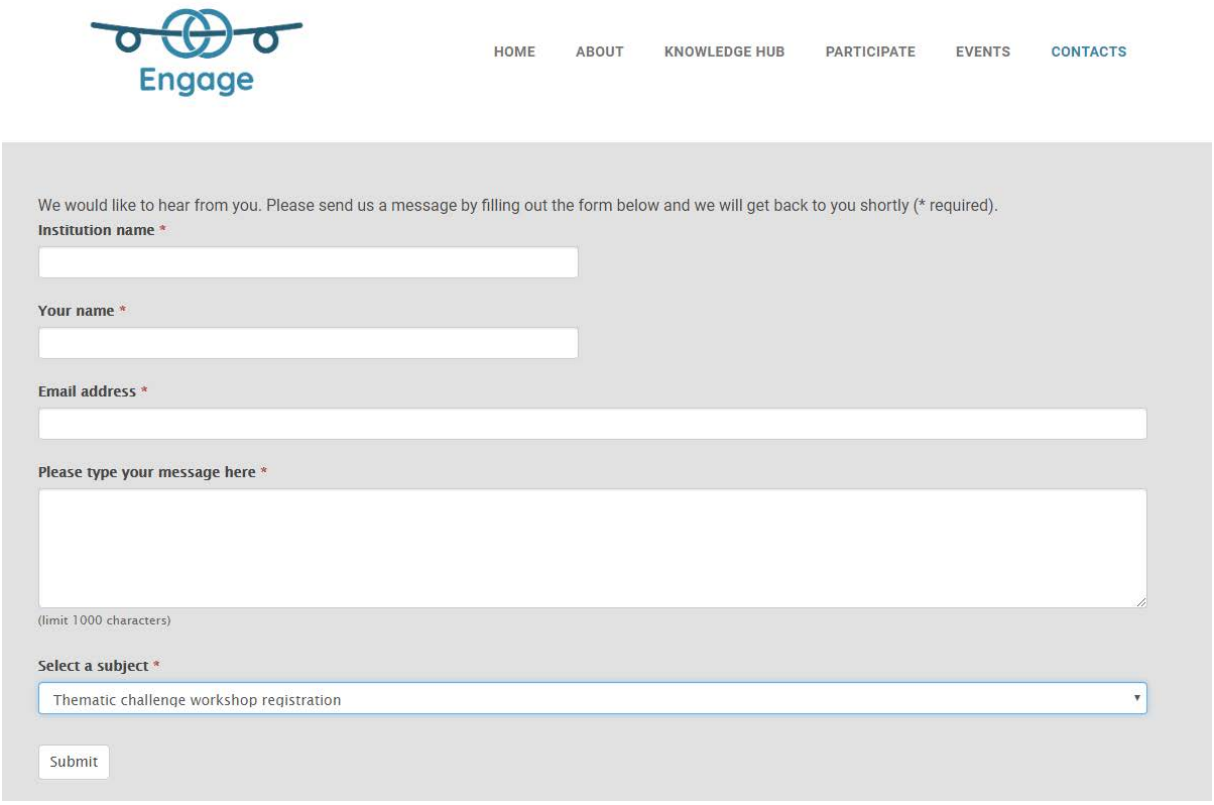

Figure 1. Workshop registration request form [1]

2.1 TC1: Vulnerabilities and global security of the CNS/ATM system

2.1.1 TC1 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.

2.1.2 TC1 workshop programme

As already mentioned, the TC1 workshop is postponed to March 2019. The initial planning was to hold the workshop on 31 October 2018, but many of the invited experts could not participate due to the bank holiday on 01 November. The second proposed date was 15 November, but this also proved unfeasible as most experts were already committed to other events (one being High Level group meeting on cybersecurity for aviation, organised 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 closes, thus moving the workshop to March 2019. However, in order to obtain additional information from the wider community, the TC1 team contacted a larger group of experts asking for feedback on the description of challenge and identification of example ideas for potential further exploration.

The received feedback identified the following threads to address at the workshop:

- Facilitate the discussion among the different aviation stakeholders (airlines, ANSPs, airlines...) in terms of systems security challenges;
- Foster a multidisciplinary community of researchers to enhance the transferability of knowledge from other disciplines (e.g. IT security) into ATM;
- Open a debate on the trade-off between the opportunities and risks of data sharing among aviation stakeholders;
- Identify the potential ATM systems' vulnerabilities and the measures that should be further investigated to mitigate those risks;
- Propose ideas on how to perform an initial security assessment and detect security threats in current and future ATM;
- Create awareness on the on-going initiatives in the CNS/ATM systems security field;
- Suggest common ideas on how to model emerging security problems.

2.2 TC2: Data-driven trajectory prediction

2.2.1 TC2 Abstract

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

2.2.2 TC2 workshop programme

Workshop date: 06 November 2018

Host: Universitat Politècnica de Catalunya (UPC) - Castelldefels Campus

Address: C. Esteve Terradas, 7. 08860 Castelldefels

C3 Building

09:30-10:00 Registration

10:00-10:15 Welcome and overview from the Engage KTN

(Dirk Schaefer, EUROCONTROL)

10:15-10:35 Foreword

(Franck Ballerini, Francis Decroly, EUROCONTROL Network Manager)

10:35-11:35 Research challenges in trajectory prediction

10:35-10:50 Trajectory prediction to assess ATM performance: Challenges and limitations identified in SESAR ER project APACHE

(Xavier Prats, UPC)

10:50-11:05 Challenges identified in the SESAR ER projects DART

(Pablo Costas and Javier Lopez-Leonés, Boeing R&T Europe)

11:05-11:20 The challenge of inferring stakeholder behaviour from data

(Rodrigo Marcos, Nommon)

11:20-11:35 Challenges identified in the SESAR ER project PARTAKE

(Miquel Àngel Piera, UAB; Juan José Ramos, ASLOGIC)

11:35-11:50 Coffee break

11:55-12:15 Operational challenges in trajectory prediction

(Sebastian Wangnick, EUROCONTROL MUAC)

12:15-12:55 Promising research avenues

12:15-12:35 Signal processing

(Jordi Vilà-Valls, CTTC and Ramon Dalmau, UPC)

12:35-12:55 Contextual modelling

(Christian Verdonk, University of Cranfield)

12:55-14:00 Lunch break

14:00-16:30 Facilitated brainstorming

14:00-14:10 Briefing

14:10-15:45 Breakout session (including coffee break)

15:45-16:30 Plenary debriefing and Pareto voting

16:30-16:45 Wrap-up and closeout

2.3 TC3: Efficient provision and use of meteorological information in ATM

2.3.1 TC3 Abstract

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

2.3.2 TC3 workshop programme

Workshop date:	13 November 2018
Host:	SESAR Joint Undertaking
Address:	Avenue de Cortenbergh 100, 1000 Brussels
Web details for access:	https://sesarju.eu/about-us/visiting-us

0915-0930	Registration, at SESAR JU reception, 4th floor
SESSION 1	**Setting the scene - ATM MET related research overview**
0930-0940	***Welcome***
	SESAR JU
0940-1000	***Introductory remarks from Engage KTN***
	Introduction to Engage and the thematic challenge
	Prof Andrew Cook, University of Westminster

Dr Tatjana Bolic, University of Trieste

1000-1100 ***MET Exploratory Research results***

Overview of the results from three MET ER projects

Prof Damian Rivas, University of Seville

1100-1125 ***SESAR2020 IR PJ18-04b MET information – progress and expected result***

Overview of MET related research in the Industrial part of SESAR

Yi Xiong, EUROCONTROL

1125-1140 ***Coffee break***

SESSION 2 Operational aspects

1140-1200 ***MET Service Provision in the future***

Overview of present and future MET service provision, with illustrative examples

Eric Petermann, EUMETNET

1200-1220 ***The urgent need for weather in ATM***

Overview of mandated MET provision for pilots and MET information needs

Klaus Sievers, European Cockpit Association

1220-1240 ***Overview of MET decision-support tools in use in USA***

Overview of US MET decision-support tools

Dr Tatjana Bolic, University of Trieste

1240-1310 ***Climate change impacts and new developments in the atmospheric sciences***

Overview of climate change impacts and new developments in the atmospheric sciences

Dr Riccardo Biondi, University of Padova

1310-1430 ***Lunch break***

SESSION 3 Facilitated discussions

1430-1545

A structured discussion, bringing together perspectives from different ATM stakeholders, ATM researchers and scientists, with the speakers and delegates. This will explore ways in which the MET challenges faced by ATM may be addressed, in moving towards more efficient MET information provision.

Three moderated break-out sessions are envisioned, to be followed by the joint discussion session where the conclusions of the individual sessions will be presented and further discussed.

Specific closing questions will include:

• what specific types of follow-up research are likely to be useful to mature the state of the art (especially those that could be addressed by catalyst funding from the Engage KTN)?

• what are the measures of success that could be used to assess the progress of the challenge?

• what are the likely barriers to prevent progress towards maturing the challenge, and how might we overcome them?

Session 1: SESAR MET research maturity and utility in the light of operational needs Wrap-up and next steps

Moderators: Luca Crecco, SJU

Prof Damian Rivas, University of Seville

Session 2: Operational requirements in the light of changing climate and new scientific developments

Moderators: Dr Tatjana Bolic, University of Trieste

Prof Andrew Cook, university of Westminster

Session 3: State-of-the-art of the MET information provision in the changing climate, and with the scientific developments - how to improve?

Moderators: Prof Manuel Soler, UC3M

Dr Riccardo Biondi, University of Padova

1545-1615 ***Coffee break***

SESSION 4 **Final discussion, wrap-up, and next steps**

1615-1645 ***Presentation of conclusions of individual discussion sessions***

Presentation of results by individual session moderators

Moderator: Prof Manuel Soler, UC3M

1645-1715 ***Joint discussion and wrap-up***

Final comments, conclusions, next steps, opportunities for funding

Moderators: Prof Manuel Soler, UC3M

Dr Tatjana Bolic

2.4 TC4: Novel and more effective allocation markets in ATM

2.4.1 TC4 Abstract

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

2.4.2 TC4 workshop programme

Workshop date:	25 October 2018
Host:	University of Westminster
Address:	309 Regent Street, London, W1B 2HW
Web details for access:	https://www.westminster.ac.uk/about-us/our-locations/maps-and-directions/regent-street

0945-1015 Registration, in reception of 309 Regent Street

SESSION 1 **Setting the scene, establishing requirements**

1015-1030	***Welcome and overview from the Engage KTN***
	University of Westminster and SESAR JU
1030-1050	***Why do we need improved models in ATM?***
	Introduction to the thematic challenge and examples from previous studies
	Prof Andrew Cook, University of Westminster
	Dr Lorenzo Castelli, University of Trieste
1050-1110	***Prioritisation mechanisms and future potential***
	Insights into current ATM slot prioritisation mechanisms and how they may be developed
	Dr Nadine Pilon, EUROCONTROL Experimental Centre
	Mats Lindholm, ML ATM Consulting
1110-1130	***Coffee break***
1130-1200	***Two SESAR Exploratory Research perspectives (COCTA, Vista)***
	Building advance trajectory pricing models; accounting for risk aversion in slot management
	Dr Radosav Jovanović, University of Belgrade
	Dr Gérald Gurtner, University of Westminster
SESSION 2	**Expanding horizons, complementary approaches**
1200-1230	***Can behavioural science model 'irrational' (real) agents?***
	Introductory insights into the approaches taken, with illustrative examples
	Benno Guenther, London School of Economics
1230-1400	***Complimentary buffet lunch***
1400-1430	***Market designs and associated challenges***
	Key principles and challenges of market design, with a focus on auctions and incentives
	Dr Alex Teytelboym, University of Oxford
SESSION 3	**Facilitated discussion**
1430-1545	

Chair: Prof Andrew Cook, University of Westminster

Facilitators: Prof Fabrizio Lillo, University of Bologna

Dr Lorenzo Castelli, University of Trieste

A structured discussion, bringing together perspectives from the fields of ATM, behavioural science and economics, with the speakers and delegates. This will explore ways in which the challenges faced by ATM may be addressed, in moving towards more efficient, yet flexible, mechanisms for the allocation of scarce resources such as slots and trajectories.

Specific questions will include:

• what specific types of follow-up research are likely to be useful to mature the state of the art (especially those that could be addressed by catalyst funding from the Engage KTN)?

• what are the measures of success that could be used to assess the progress of the challenge?

• what are the likely barriers to prevent progress towards maturing the challenge, and how might we overcome them?

SESSION 4 **Wrap-up, next steps, networking**

1545-1600 ***Wrap-up and next steps***

Conclusions, next steps, opportunities for funding

Prof Andrew Cook, University of Westminster

Formal close

1600-1630 ***Networking coffee – future collaborations***

3 Workshop conclusions

All four thematic challenge workshops were planned to be held in 2018, but due to the difficulties finding a date convenient for invited experts, the TC1 workshop had to be postponed. However, the TC1 team contacted an extended group of experts in order to update the TC1 description text, so that it can be of use to the parties interested in the catalyst funding Call.

3.1 TC1 Description and update from consultation

New date and venue for TC1 workshop: March 2019, to be held at the SJU offices in Brussels, Belgium.

3.1.1 TC1 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.

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 [3]. 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 [4]; ADS-B false-aircraft transmissions – so-called false data injection attacks (FDIA; e.g. see [5]); and, attacking key infrastructure elements such as SWIM (system wide information management; e.g. see [3]).

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 [6], 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 cybersecure 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.

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.

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 [7], 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.

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 [8]. 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 [9] 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.
- [10] organised a workshop on technical standards to initiate the discussion about future rule-making and standardisation for cybersecurity in aviation.
- The GAMMA project [11] 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 [12] 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."

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 Update from consultation

In order to further develop specific lines of potential research activities for this challenge, an internal consultation was performed involving Engage partners and thematic challenge 1 proposers. The result of this exercise is presented below and will be complemented by a workshop (expected to take place in Spring 2019).

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.

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.

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.

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.

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

1. Assessing the security of ATM elements and relationships to identify vulnerabilities and ensure protection against global threats;
2. Enhancing cybersecurity of systems without having to replace and refit, including certification, legal and liability issues;
3. Building data-sharing architectures capable of connecting and providing access to distributed data while preserving privacy;
4. Adapting mental models to prepare operators to understand and manage cyber threats
5. Updating software and firmware of IT components to resolve security vulnerabilities of critical infrastructures;
6. Further researching security analyses of aviation-specific protocol implementations (vulnerabilities, trust, software libraries).

Link to the challenge description:

http://engagektn.com/wp-content/uploads/2018/11/Thematic-challenge-1-Ed-2.0.pdf

3.1.3 TC1 Poster for SESAR Innovation Days

Figure 2. TC1 – CNS Vulnerability and security, poster for SESAR Innovation Days 2018

3.2 TC2 Description and workshop conclusions

3.2.1 TC2 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 indexes, take-off weights) are important shortcomings of the state of the art, regarding pre-tactical and tactical trajectory prediction technologies. Indeed, various stakeholders need different aspects of TP *across all phases* of operations, and 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 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') behavioural drivers from historical data and enhance tactical and pre-tactical trajectory prediction;
- aggregation of probabilistic predictions into probabilistic traffic counts reducing the uncertainty when predicting traffic volumes;
- development of tools for the identification of 'hotspots' and the evaluation of different ATFCM measures;
- bridging the gaps between the temporal phases of ATFCM.

All of these developments could be integrated into the Network Manager's and/or flight operations centres' 4D trajectory planning tools, leading to enhanced collaboration in trajectory management, 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[1].

Robust demand forecast is a fundamental requirement to support the Trajectory-Based Operations paradigm and a key enabler of ATFCM service delivery. Network 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, each one with its associated uncertainty and granularity levels. This presents a series of challenges, and notably a lack

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

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 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 data analysis and visualisation, present opportunities to develop new modelling techniques to improve trajectory prediction performance and robustness by:

- integrating and analysing different sources of flight-relevant information;
- the application of new modelling methods, such as machine-learning techniques, causal modelling and statistical signal processing solely, or in combination with traditional methods;
- inferring airspace users' drivers from historical data;
- engaging airspace users to collaborate and benefit from potential air traffic management interventions (better) fitting their business needs.

3.2.2 TC2 Workshop conclusions

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, operations planning by AUs at the pre-tactical (e.g. flight dispatch) and tactical levels (e.g. self-separation, in-flight trajectory updates) 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 of flight plan data in the pre-tactical planning phases, when the Network Manager together with national service providers 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.

The availability and quality of relevant data is a prerequisite for accurate TPs. 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. TPs are 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.

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

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

Link to the challenge description updated with workshop conclusions:

http://engagektn.com/wp-content/uploads/2018/12/Thematic-challenge-2-Ed-2.0.pdf

Link to the presentations:

http://engagektn.com/wp-content/uploads/2018/11/Engage-TC2-workshop-presentations-part1.zip

http://engagektn.com/wp-content/uploads/2018/11/Engage-TC2-workshop-presentations-part2.zip

3.2.3 TC2 Poster for SESAR Innovation Days

Figure 3. TC2 – Data driven trajectory prediction, poster for SESAR Innovation Days 2018

3.3 TC3 Description and workshop conclusions

3.3.1 TC3 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 this 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[2] on climate adaptation by airports);
- En-route – winds impact aircraft speed, weather cells can cause ANSPs to change flights' trajectories, etc.;
- Airlines – trajectory changes[3], delays and schedule disruption occur, resulting in various types of cost (e.g. passenger reaccommodation);
- Network level – the Network Manager 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 still not in place in the European network.

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-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

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

[3] Improved trajectory prediction *per se* falls within the remit of Engage thematic challenge 2.

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[4] 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 National Meteorological and Hydrological Services (NMHS), some Air Traffic Service (ATS) 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 [13] 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 ([14]). 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, [15] (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 multidecadal variability ([16], [17], [18]), and analyses of extreme wind speeds highlight significant upward trends in central, northern and western Europe ([19], [20]). 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 [21]. 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 ([22], [23], [24]). A belt stretching from the United Kingdom to Poland will experience an increase in extreme storminess and wind speed, while southern Europe and the Mediterranean will rather see a decrease in strong winds ([22], [25]).

It must be recognised that recent years have witnessed important improvements in observational (e.g., satellites, LIDARs) 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

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

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 both learning about improvements in the atmospheric sciences, and about ATM needs in the light of the uncertainty that weather imposes on the network (and related uncertainty management) 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.

3.3.2 TC3 Workshop conclusions

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 behind the lack of a consistent and agreed weather 'picture' for ATM in Europe. The Network Manager and several MET offices are working on the creation and usage of European forecasts for network management.

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 these new MET products and take advantage for better planning of resources.

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 Network Manager 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 most cited barriers to the progress of MET and MET/ATM research were 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.

Link to the challenge description updated with workshop conclusions:

http://engagektn.com/wp-content/uploads/2018/11/Thematic-challenge-3-Ed-2.0.pdf

Link to the presentations:

http://engagektn.com/wp-content/uploads/2018/11/Engage-TC3-workshop-presentations-part1.zip

http://engagektn.com/wp-content/uploads/2018/11/Engage-TC3-workshop-presentations-part2.zip

3.3.3 TC3 Poster for SESAR Innovation Days

Figure 4. TC3 – Efficient use of MET data, poster for SESAR Innovation Days 2018

3.4 TC4 Description and workshop conclusions

3.4.1 TC4 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 (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 principles, matching market, 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[5], under different types of uncertainty and information sharing? Which mechanisms are more robust against behavioural biases ('irrationalities') 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)?

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 below:

- **Loss aversion**
    - losses are worse (have more disutility) than gains are good (have utility), e.g. avoiding a €1k slot delay is preferred to an (immediate) €1k 'slot credit'
- **Endowment (inertia) effects**

[5] Improved trajectory prediction *per se* falls within the remit of Engage thematic challenge 2.

  - a higher value is attributed to a good already owned, e.g. “we will ‘pay’ as much to avoid an initial 15 minutes of slot delay, as to avoid a further (more expensive) 15 minutes of delay”

- **Path dependencies**
  - the value of a good depends on the path of acquisition, e.g. “we protected this slot today after sacrificing ten flights last week, so there is no way we are going to trade it today”

- **Future discounting**
  - the value of a good depends on when it is consumed, e.g. one 30-minute slot improvement today is worth two identical improvements next week

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). Classically, market forces are often assumed to establish rationality and, ultimately, to produce a predictable equilibrium – although this is often not the case.

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, [26] 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. However, notwithstanding limited examples considering actual human behaviour in the context of wider transport planning and environmental policy (e.g., [27]; [28]), there are no known formal considerations of the applications of behavioural science in ATM.

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 ([29]; [30]), auctioning for strategic airport slots ([31]; [32]), and controlling tactical delay distributions to minimise propagated delay and increase adherence to (strategic) airport slots at coordinated airports [33]. Further development opportunities lie ahead, in that modelling in these domains variously investigates the optimal use of limited capacities but (necessarily) assumes unbounded 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 their true preferences in order to gain a strategic advantage over their competitors” [34]. 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" [35].

Whilst **(strategic) airport slots are not in scope for this challenge**, let us consider briefly a current 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 apportionment and selective flight protection [36]. It is also exploring future options for even greater flexibility regarding cost minimisation and equity for 'low volume' airspace users 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 unbounded rationality and utility maximisation [37].

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? What new technologies might be appropriate to support the negotiation of tactical contracts? For example, might cryptoeconomic tools[6] have a role to play in delivering 'smart' contracts? From a user-acceptability perspective, could such tools deploy a centralised market with real money, or would only 'credits' be acceptable?

3.4.2 TC4 Workshop conclusions

Behavioural science could be used to better capture 'irrational' (non-normative) behaviour from airlines in future, and build improved 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. 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? The objective is to offer airspace users improved choice, whilst avoiding undesirable behaviours, such as gaming of the system. Improved definitions of 'equity' and 'fairness' are needed, potentially differentiating or consolidating the two terms, examining the definitions and trade-offs across

[6] Note that vulnerabilities and global security of the CNS/ATM system falls within the remit of Engage thematic challenge 1.

different stakeholders (e.g. airports treating all flights equally, unlike airlines), plus trade-offs with flexibility. Are there ways in which tactical uncertainty could be exploited to offer more flexibility to airspace users? There is 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. Further work is also needed on the precise definition of the 'best' trajectory[7], 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 [30]) 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[8], which investigated how 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 ([38] [39]).

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 airspace user's response to the evolving traffic situation as they adapt from the originally-filed flight plan. Integrating new behavioural models with a more systematic exploration of the impact of computer-based flight planning and how this responds to different scenarios, with models of feedback loops and inclusion of machine learning could also be beneficial[7]. 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. Ultimately, can the two main themes of this challenge be integrated, i.e. embedding agent 'irrationality' inside the development of new market mechanisms?

[7] Improved trajectory prediction *per se* falls within the remit of Engage thematic challenge 2.

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

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

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

Link to the challenge description updated with workshop conclusions:

http://engagektn.com/wp-content/uploads/2018/11/Thematic-challenge-4-Ed-2.0.pdf

Link to the presentations:

http://engagektn.com/wp-content/uploads/2018/11/Engage-TC4-workshop-presentations.zip

3.4.3 TC4 Poster for SESAR Innovation Days

Figure 5. TC4 – Novel market mechanisms in ATM, poster for SESAR Innovation Days 2018

4 Conclusions and next steps

4.1 Lessons learned

The format chosen for the TC workshops worked well, and was well received by the participants:

1. the workshop should last one day;
2. be free of charge to attend;
3. involve around 30 participants (to stimulate good discussion);
4. have a strong emphasis on discussion regarding the maturing of the challenge, with facilitated discussion, rather than simply packing in a series of presentations;
5. interdisciplinarity is strongly encouraged.

In the process of organising the workshops, the following lessons emerged:

1. Having the presentations as discussion starters is a good way of eliciting fruitful debate between the participants. Workshop organisers should continue to strive to steer the speakers in this direction – the talks by speakers should be concise and posing questions to be debated in the subsequent workshop sessions.
2. 6 speakers is the *maximum* for a good introduction to the topic and planned discussion, more than this tends to impact negatively on the amount of constructive discussion time.
3. Participation of academia and research institutions was significant and there were no problems of attracting this audience.
4. Participation from industry varied from workshop to workshop, but it was lower than that of academia. Whilst this is typical of such events (e.g. also the SIDs) this could probably be improved through organising the workshops with longer lead times (the schedule for Engage was very tight in 2018, although three workshops were still organised between the evaluation of the topics submitted, and the SIDs) and better dissemination directly to IR partners (where SJU might be able to add further support).
5. As this was the first round of TC workshops, a lot of effort was spent in the organisation. A significant part of the effort was on the challenge proposers and Engage support in first shaping the challenge itself, as each challenge had a few proposers and there was a need to streamline these into a coherent, single vision. The Engage support members served as focal points that collected the proposers' input and shaped it into the final description. The process took considerable time even though all the proposers were enthusiastic and proactive. These demands on time should be kept in mind for future thematic challenge calls.

6. For a one-day workshop, it would be good to host it in a location that is easily reachable. That is to say, a location that can allow for a day trip for most of the participants.
7. The flexible registration process for the workshop worked well. It was possible to register through the Engage website and by confirming the presence to the Engage team member organiser. As the number of participants of each workshop was around the limit of 30, there was no need for refusing anyone in this round.
8. The definition of the challenge, workshop agenda, discussion moderations and result write-ups were performed jointly by the challenge proposers, SJU colleagues and Engage members. This resulted in very interesting workshops, with lively debates. The result write-ups took considerable time as it involved multiple persons. In the future workshops, it might be better for Engage members to take the lead on this, although this has to be balanced against managing the KTN effort budget and allowing the proponents to be active in shaping their challenges.
9. Participants were enthusiastic about the workshops and Engage already received several inquiries about the possibility of synchronising and co-organising the TC workshops and some other, TC-related initiatives.

Recommendations:

1. Have workshop programmes (with confirmed speakers) as much as possible in advance (ideally two months, where possible) of the date to allow ample time for publication of workshops and invitations, especially if there are certain types of stakeholders that we want to reach.
2. Do not have more than six speakers.
3. Ask the SJU to kindly further extend the invitations to industry (e.g. IR projects), stressing the value of participation. This has been done, but having more lead time (see point 1 above) could improve the process.
4. Engage members to somewhat more firmly drive the final closure process (i.e. collection of results and the final conclusion write-ups), appointing a specific member for each workshop, before it is launched.

4.2 Next steps

The workshop conclusions (and consultation update) were presented at the 8th SESAR Innovation Days, both during the presentations and through the posters (see Sections 3.1.3, 3.2.3, 3.3.3, 3.4.3).

The key next steps for this task are as follows:

1. The remaining TC1 workshop (Vulnerabilities and global security of the CNS/ATM system) to be held at the SJU offices (Brussels, Belgium) in March 2019;
2. A review of the:
    - future challenge development;
    - associated workshop programme;
    - possible requirement for a further invitation for challenge topic;
    - potential integration with the 2019 summer school.
3. The second wave of the thematic challenge workshop programme will follow during 2019.

The second and third steps are closely linked, as the third step will follow after the review step is completed. As the thematic challenges are closely linked with both the PhDs and the catalyst funding Call, the Engage consortium is awaiting the conclusion of both Calls, to be able to review and, if needed, adjust the challenge development. Thematic challenges will be variously taken up by the PhDs, and the continuing operation of these challenges will also act as a platform of support for such PhDs. This is thus a two-way process.

In case there are no PhD proposals falling under a certain thematic challenge, and there are no corresponding proposals in response to the thematic challenge Call (closing 15 February 2019), the Engage consortium will review the usefulness of continuing the development of any such specific challenges and assess whether a new invitation for challenge topic will be needed.

The consortium expects to be able to perform this review in March 2019, and at that time to start scheduling the 2019 workshop programme.

The first Engage summer school is to be held at the beginning of September 2019 in Belgrade, Serbia. Having one challenge workshop held just before or after the summer school, at the same location, might be a good synergy and efficient use of Engage and external resources. Further inputs from SJU on related issues are also in progress. Indeed, the whole review process and the second wave of thematic workshops will be discussed and agreed with SJU colleagues.

5 References

[1] Engage project, "Engage KTN," 29 November 2018. [Online]. Available: http://engagektn.com/.

[2] Engage project, "D3.4 Thematic challenges priming report for first workshops," 2018a.

[3] M. Everdij, B. Gijsen, A. Smulders, T. Verhoogt and R. Wiegers, "Cyber-security management of ATM services: are we ready for the future?," *Aviation security international,* pp. 34-36, 2016.

[4] M. Strohmeier, V. Lenders and I. Martinovic, "On the Security of the Automatic Dependent Surveillance-Broadcast Protocol," *IEEE Communications Survey & Tutorials,* vol. 17, no. 2, pp. 1066-1087, 2015.

[5] A. Cretin, B. Legeard, F. Peureux and A. Vernotte, "Increasing the Resilience of ATC systems against False Data Injection Attacks using DSL-based testing," Castelldefels, Spain, 2018.

[6] Industry Consultation Body, "Information paper on Industry Developments in ATM CyberSecurity," 2017.

[7] SESAR JU, "SESAR Strategy and Management Framework Study for Information Cyber-Security," 2015.

[8] CANSO, "CANSO Cyber Security and Risk Assessment Guide," 2014. [Online]. Available: https://www.canso.org/canso-cyber-security-and-risk-assessment-guide.

[9] EUROCONTROL, "Agency Research Team Workshop 'ATM SEcurity and Cybersecurity'," 23 March 2016. [Online]. Available: https://www.eurocontrol.int/events/agency-research-team-workshop-atm-security-and-cybersecurity. [Accessed November 2018].

[10] EASA, EUROCAE, "Workshop on Cybersecurity in Aviation," 31 May 2017. [Online]. Available: https://www.easa.europa.eu/sites/default/files/dfu/Cybersecurity%20workshop%20Report%20-%20final.pdf.

[11] GAMMA project, "- Global ATM Security Management Project, European Union's Seventh research and innovation Framework Programme.," 2017. [Online]. Available: http://www.gamma-project.eu.

[12] European Strategic Coordination Platform, 2017. [Online]. Available: https://www.easa.europa.eu/newsroom-and-events/news/high-level-conference-cybersecurity-civil-aviation-krakow-declaration.

[13] Commission Implementing Regulation (EU) No 716/2014, *COMMISSION IMPLEMENTING REGULATION (EU) No 716/2014 on the establishment of the Pilot Common Project supporting the implementation of the European Air Traffic Management Master Plan,* Official Journal of European Union, 2014.

[14] Ø. Hov, U. Cubasch, E. Fischer, P. Höppe, T. Iversen, N. Kvamstø, Z. Kundzewicz, D. Rezacova, D. Rios, F. Santos, B. Schädler, O. Veisz, C. Zerefos, R. Benestad, J. Murlis, M. Donat, G. Leckebusch and U. Ulbrich, "Extreme weather events in Europe: preparing for climate change adaptation," Norwegian Meteorological Institute, 2013.

[15] E. Black, D. Brayshaw and C. Rambeau, "Past, present and future precipitation in the Middle East: insights from models and observations," *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences,* vol. 368, p. 5173–5184, 2010.

[16] H. Alexanderson, H. Tuomenvirta, T. Schmith and K. Iden, "Trends of Storms in NW Europe derived from an updated pressure data set," *Climate Reserarch ,* vol. 14, pp. 71-73, 2000.

[17] L. Barring and H. Von Storch, "Scandinavian storminess since about 1800," *Geophysical REsearch Letters,* vol. 31, no. 20, 2004.

[18] J. Wang, J. Zhang, E. Watanabe, M. Ikeda, K. Mizobata, J. Walsh, X. Bai and B. Wu, "Is the Dipole Anomaly a major driver to record lows in Arctic summer sea ice extent?," *Geophysical Research Letters,* vol. 36, no. 5, 2009.

[19] M. Donat, D. Renggli, S. Wild, L. Alexander, G. Leckerbusch and U. Ulbrich, "Reanalysis suggests long-term upward trends in European storminess since 1871," *Geophysical Research Letters,* vol. 38, no. 14, 2011b.

[20] S. Bronnimann, O. Martius, H. von Waldow, C. Welker, J. Luterbacher, G. Compo, P. Sardeshmukh and T. Usbeck, "Extreme winds at northern mid-latitudes since 1871," *Meteorologische Zeitschrift,* vol. 21, pp. 13-27, 2012.

[21] M. Beniston, D. Stephenson, O. Christensen, C. Ferro, C. Frei, S. Goyette, K. Halsnaes, T. Holt, K. Jylha, B. Koffi, J. Palutikof, R. Scholl, T. Semmler and K. Woth, "Future extreme events in European climate: an exploration of regional climate model projections," *Climatic Change,* vol. 81, pp. 71-95, 2007.

[22] G. Leckebusch, U. Ulbrich, J. Pinto, T. Spangehl and S. Zachsarias, "Analysis of frequency and intensity of European winter storm events from a multi-model perspective, at synoptic and regional scales," *Climate Research,* vol. 31, pp. 59-74, 2006.

[23] J. Pinto, S. Zacharias, A. Fink, G. Leckebusch and U. Ulbrich, "Factors contributing to the development of extreme North Atlantic cyclones and their relationship with the NAO," *Climate dynamics,* vol. 32, pp. 711-737, 2009.

[24] U. Ulbrich, G. Leckebusch and P. J.G., "Extratropical cyclones in the present and future climate: a review," *Theoretical and Applied Climatology,* vol. 96, pp. 117-131, 2009.

[25] M. Donat, G. Leckebusch, S. Wild and U. Ulbrich, "Future changes in European winter storm losses and extreme wind speeds inferred from GCM and RCM multi-model simulations," *Natural Hazards and Earth System Science,* vol. 11, pp. 1351-1370, 2011a.

[26] M. Whitehead, R. Jones, R. Howell, R. Lilley and J. Pykett, "Assessing the global impact of the behavioural sciences on public policy," Economic and Social Research Council , 2014.

[27] E. Avineri, "On the use and potential of behavioural economics from the perspective of transport and climate change," *Journal of Transport Geography,* vol. 24, pp. 512-521, 2012.

[28] M. Garcia-Sierra, J. van den Bergh and C. Miralles-Guasc, "Behavioural economics, travel behaviour and environmental transport policy," *Transportation Research Part D,* vol. 41, pp. 288-305, 2015.

[29] T. Bolić, L. Castelli and D. Rigonat, "Peak-load pricing for the European Air Traffic Management system using modulation of en-route charges," *European Journal of Transport and Infrastructure Research,* vol. 17, no. 1, pp. 136-152, 2017.

[30] L. Castelli, R. Pesenti and A. Ranieri, "The design of a market mechanism to allocate Air Traffic Flow Management slots," *Transportation Research Part C,* vol. 19, no. 5, pp. 931-943, 2011.

[31] R. De Neufville and A. Odoni, Airport Systems:Planning, Design and Management, Second Ed., McGraw-Hill, 2013.

[32] R. Herranz, D. Toribio, M. Ramírez, F. Villafáñez, J. Araúzo, D. Poza, N. Alsina, L. Garrigó, L. Castelli and T. Bolić, "Price-setting auctions for airport slot allocation: a multi-airport case study," Bologna, Italy, 2015.

[33] N. Ivanov, F. Netjasov, R. Jovanović, S. Starita and A. Strauss, "Air Traffic Flow Management slot allocation to minimize propagated delay and improve airport slot adherence," *Transportation Research Part A,* vol. 95, pp. 183-197, 2017.

[34] A. Jacquillat and A. Odoni, "A roadmap toward airport demand and capacity management," *Transportation Research Part A,* vol. 114, pp. 168-185, 2018.

[35] D. Gillen, A. Jacquillat and A. Odoni, "Airport demand management: The operations research and economics perspectives and potential synergies.," *Transportation Research Part A,* vol. 94, pp. 495-513, 2016.

[36] N. Pilon, S. Ruiz, A. Bujor, A. Cook and L. Castelli, "Improved flexibility and equity for airspace users during demand-capacity imbalance - an itnroduction to the user-driven prioritisation process," Delft, Netherlands, 2016.

[37] S. Ruiz, L. Guichard and N. Pilon, "Optimal delay allocation under high flexibility conditions during demand-capacity imbalance," Belgrade, Serbia, 2017.

[38] J. Schummer and A. Abizada, "Incentives in landing slot problems," *Journal of Economic Theory,* vol. 170, pp. 29-55, 2017.

[39] J. Schummer and R. Vohra, "Assignment of arrival slots," *American Economic Journal: Microeconomics,* vol. 5, no. 2, pp. 164-185, 2013.

[40] Engage project, "Grant Agreement 783287, Ref. Ares(2017)6114946 - 13/12/2017," 2017.

6 Acronyms

ACI	Airports Council International
ADS-B	Automatic dependent surveillance - broadcast
ANSP	Air Navigation Service Provider
ATC	Air Traffic Control
ATFCM	Air Traffic Flow Control Management
ATFM	Air Traffic Flow Management
ATM	Air traffic management
ATS	Air Traffic Services
AU	Airspace user
CD&R	Conflict Detection and Resolution
CNS	Communication, navigation and surveillance
DCB	Demand-capacity balancing
EASA	European Aviation Safety Agency
EATMA	European ATM architecture
EFB	Electronic flight bag
ER	Exploratory Research (within SESAR JU programme)
ESCP	European Strategic Coordination Platform
EU	European Union
EUROCAE	European Organisation for Civil Aviation Equipment
FDIA	False data injection attacks
ICAO	International Civil Aviation Organisation
ICB	Industry Consultation Body
IPCC	Intergovernmental Panel on Climate Change
IR	Industrial Research (within SESAR JU programme)
LIDAR	Light detection and ranging
MET	Aviation meteorology
MTCD	Medium-term conflict detection

NM	Network Manager
NMHS	National Meteorological and Hydrological Services
NWP	Numerical weather prediction
SESAR	Single European Sky ATM research
SJU	SESAR Joint Undertaking
STCA	Short-term conflict alert
SWIM	System Wide Information Management
TBO	Trajectory Based Operations
TC	Thematic challenge
TCAS	Traffic collision avoidance system
TP	Trajectory prediction
TPI	Traffic Prediction Improvement
TRL	Technology Readiness Level
UDPP	User-Driven Prioritisation Process
UN	United Nations

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