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Faculty of Transportation Sciences

Bc. JAN REGINÁČ

Identification of Research Potential of the Department of Air Transport

Master's thesis

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CZECH TECHNICAL UNIVERSITY IN PRAGUE
Faculty of Transportation Sciences
Dean's office
Konviktská 20, 110 00 Prague 1, Czech Republic

K621 .... Department of Air Transport

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Bc. Jan Regináč

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- Overview of Future plans for ATM system
- Creation of a mind map and identification of the most up-to-date scientific research sections for the years 2019 to 2022.
- Introduction of the identified areas for further research
- Comparison of research capabilities of Department of Air Transport with identified parts for research.
- Summary and recommendations for the Department of Air Transport + Roadmap with a view to a year 2025.

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L.S.

doc. Ing. Jakub Kraus, Ph.D.
head of the Department of Air Transport

doc. Ing. Pavel Hrubeš, Ph.D.
dean of the faculty

I confirm assumption of master's thesis assignment.

Bc. Jan Regináč
Student's name and signature

Prague .... July 27, 2018

Abstract

With a constant growth of Air Transport around the world, there are significant needs for innovation and modernisation of existing ATM/CNS systems. A purpose of this thesis was to identify the most up-to-date research areas in a global ATM system, compare the key R&D sections with research capabilities of the Department of Air Transport at the Czech Technical University and subsequently recommend a view to the year 2025 in a Roadmap with steps for further exploration. The first part of the thesis briefly introduces programmes of different organisations focused on ATM modernisation. The second part is focused on the process of identification which was done by the quantitative approach using a created mind map as an instrument for further identification as well as by the qualitative approach in the form of in-depth research. Results from both approaches were compared to the research capabilities of the Department of Air Transport. The last part of the thesis summarises outcomes and provides the areas as well as topics that are in alignment with the capabilities of the Department of Air Transport.

Keywords

ATM, CNS, Air Transport, modernisation, research, innovation, SESAR, GANP, European ATM Master Plan

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V Praze dne 24.5.2019

Bc. Jan Regináč

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1. Introduction

Air Transport around the world is continuously growing, and there are significant needs for innovation and modernisation of existing ATM (Air Traffic Management) systems. Air Traffic Management is a critical element in the air transport value chain and the key to connecting regions. To ensure the sustainability and competitiveness of aviation, a high-performing ATM system is necessary. ATM modernisation needs to reflect a greater focus on increased efficiency and effectiveness while sustaining or even improving the levels of safety and security. At the same time, it must recognise the need to provide solutions to address critical future challenges for instance cybersecurity, autonomy, digitalisation and many others.

The purpose of this thesis is to identify the most up-to-date R&D areas addressing such challenges and subsequently compare the identified areas with research capabilities of the Department of Air Transport (DAT) at the Czech Technical University in Prague as well as to determine the potential for Department's current or future research.

The first part of the thesis is devoted to the well-arranged overview of leading organisations involved in modernising ATM as well as introducing their programmes, visions and objectives. European SESAR (Single European Sky ATM Research) can be considered as a leader in the innovation of ATM systems; hence, its SESAR 2020 programme served as a primary information source for identifying the actual research areas.

Next chapter describes the SESAR R&D progress in more details, and above all, the methodology of identification is provided. The identification process is done with the help of created mind map and Matlab software in the case of a quantitative approach. On the other hand, qualitative method relied on in-depth research of strategic documents of SESAR. Both methods propose a list of themes that are later on compared with DAT research capabilities.

The chapter dealing with comparison contains the list of projects and grants where DAT has participated as well as concluded structured interviews conducted with experts working on ATM modernisation at the ATM systems laboratory at DAT. Furthermore, this chapter provides the comparison aiming at the possible intersection of identified areas with areas of research undertaken at DAT.

Eventually, the last chapter concludes the thesis and provides the recommendations accompanied by a roadmap with a view to the year 2025.

This thesis intends to serve also as a foundation of the current R&D themes that can be further explored either by students in the framework of final theses or research conducted at DAT.

2. Overview of future plans for ATM system

Air traffic management has witnessed some critical improvements in recent decades, and yet, a considerable remainder of the global ATM system is still limited by conceptual approaches that arose in the twentieth century. These legacy ATM capabilities limit air traffic capacity and growth and are responsible for unnecessary gas emissions being deposited into our atmosphere. A fully-harmonised global air navigation system built on modern performance-based procedures and technologies is a solution to these concerns. This goal has been on the minds of Communications, Navigation and Surveillance/Air Traffic Management (CNS/ATM) planners for many years. Because technology never stands still, the realisation of a strategic path to such a globally harmonised system has proven elusive. Ongoing air navigation improvement programmes being undertaken by a number of ICAO member states (SESAR in Europe; NextGen in the United States; CARATS in Japan; SIRIUS in Brazil, and others in Canada, China, India and the Russian Federation) working on a solution to this impasse [1].

Only by bringing together the states and stakeholders from every corner of the aviation community can a viable solution to twenty-first century air navigation be determined.

Each of the improvement programmes presents their plans for future air navigation that later serves as a tool for the implementation of modern systems as well as a determination of subsequent research and development areas.

ICAO with Global Air Navigation Plan (GANP) happens to be the significant leader providing a vision of the evolution of the global ATM system and the potential requirements to industry. Furthermore, obliges states to map their national or regional programmes against GANP providing them greater certainty of investment.

The GANP is the strategy to achieve global interoperable air navigation system, for all users during all phases of flight, that meets agreed levels of safety, provides for optimum economic operations, is environmentally sustainable and meets national security requirements. The GANP is being evolved to serve as a worldwide reference to transform the air navigation system evolutionarily so that no state or stakeholder is left behind [1]. A detailed description of the improvement programs is provided below.

2.1. ICAO Global Air Navigation Plan 2016–2030

The Global Air Navigation plan has its roots in an appendix to a 1993 report on what was then termed the Future Air Navigation System (FANS). These recommendations were first presented as the FANS Concept and later became referred to more generally as CNS/ATM.

The FANS initiative had answered a request from ICAO member states for planning recommendations on how to address air transport's steady global growth through the coordination of emerging technologies. As research and development into these technologies accelerated rapidly during the 1990s, the plan and its concepts advanced with them.

A standalone version was published as the ICAO Global Air Navigation Plan for CNS/ATM Systems (Doc 9750) in 1998, the second edition of which was released in 2001. During this period the Global Plan served to support state and regional planning and procurement needs surrounding CNS/ATM systems.

By 2004, ICAO member states and the air transport industry at large had begun to encourage the transitioning of the Global Plan's concepts into more practical, real-world solutions. Two ATM implementation roadmaps, made up of specific operational initiatives, were consequently developed on a collaborative basis by dedicated ICAO/industry project teams.

The operational initiatives contained in the roadmaps were later renamed Global Plan Initiatives (GPIs) and incorporated into the third edition of the GANP [1].

The fourth edition of Global Air Navigation Plan represents a rolling, 15-year strategic methodology which leverages existing technologies and anticipates future developments based on state (industry) agreed operational objectives. The Block Upgrades are organised in non-overlapping six-year time increments starting in 2013 and continuing through 2031 and beyond. This structured approach provides a basis for sound investment strategies and will generate commitment from states, equipment manufacturers, operators and service providers.

The GANP explores the need for more integrated aviation planning at both the regional and state level and addresses required solutions by introducing the consensus-driven Aviation System Block Upgrades (ASBU) systems engineering modernisation strategy.

The Global Air Navigation Plan's Aviation System Block Upgrades methodology is a programmatic and flexible global systems engineering approach that allows all member states to advance their air navigation capacities based on their specific operational requirements. The Block Upgrades will enable aviation to realise the global harmonisation, increased capacity, and improved environmental efficiency that modern air traffic growth now demands in every region around the world. Besides, it identifies issues to be addressed in the near future alongside financial aspects of aviation system modernisation. The increasing importance of collaboration and partnership as aviation recognises and addresses its multidisciplinary challenges ahead is also stressed. The GANP also outlines implementation issues involving the near-term Performance-Based Navigation (PBN) and Block 0 Modules and the Planning and Implementation Regional Groups (PIRGs) that will be managing regional projects.

The GANP outlines ICAO's 10 key civil aviation policy principles guiding global, regional and state air navigation planning [1].

ICAO's 10 Key civil aviation policy principles [1]:

1. Commitment to the implementation of ICAO's Strategic Objectives and Key Performance Areas
2. Aviation safety is the highest priority
3. Tiered approach to air navigation planning
4. Global Air Traffic Management Operational Concept (GATMOC)
5. Global air navigation priorities
6. Regional and state air navigation priorities
7. Aviation System Block Upgrades (ASBUs), Modules and Roadmaps
8. Use of ASBU Blocks and Modules
9. Cost-benefit and financial issues
10. Review and evaluation of air navigation planning

2.1.1. Aviation system block upgrades (ASBU)

The Global Air Navigation Plan introduces a system engineering planning and implementation approach which has been the result of extensive collaboration and consultation between ICAO, its member states and industry stakeholders.

ICAO developed the Block Upgrade global framework primarily to ensure that aviation safety will be maintained and enhanced, that ATM improvement programmes are effectively harmonised, and that barriers to future aviation efficiency and environmental gains can be removed at a reasonable cost.

The Block Upgrades incorporate a long-term perspective matching that of the three companion ICAO air navigation planning documents. They coordinate clear aircraft and ground-based operational objectives together with the avionics, data link and ATM system requirements needed to achieve them. The overall strategy serves to provide industry-wide transparency and essential investment certainty for operators, equipment manufacturers and ANSPs. The core of the concept is linked to four specific and interrelated aviation performance improvement areas, namely [1]:

1. Airport operations;
2. Globally-interoperable systems and data;
3. Optimum capacity and flexible flights; and
4. Efficient flight paths.

The performance improvement areas and the ASBU Modules associated with each have been organised into a series of four Blocks (Block 0, 1, 2 and 3) based on timelines for the various capabilities they contain, as illustrated in Figure 2.1.

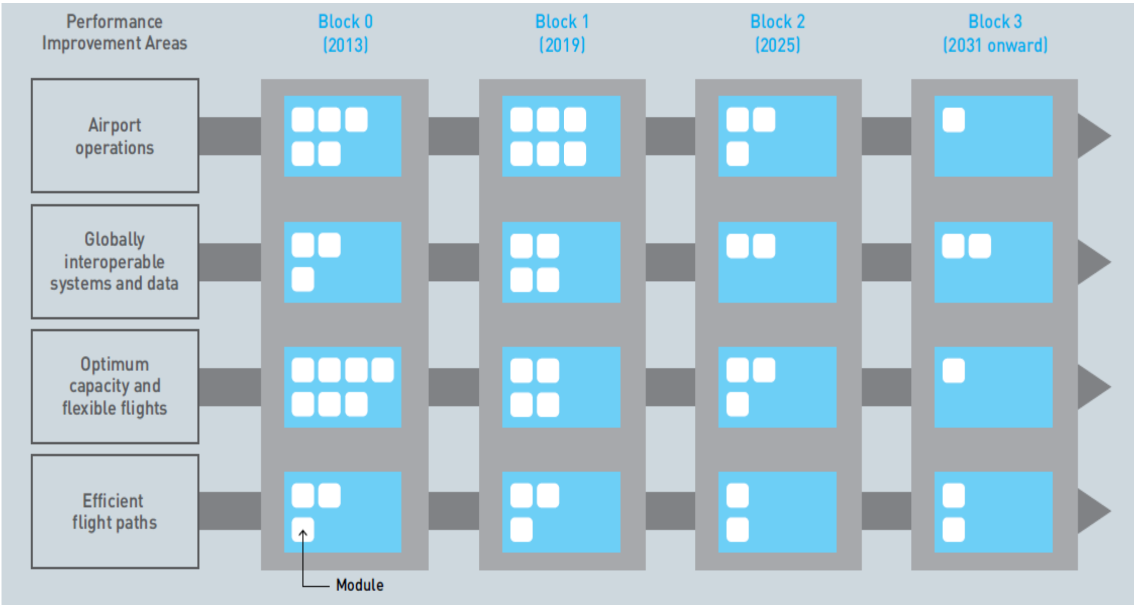

Figure 2.1: Depicting Block 0–3 availability milestones, performance improvement areas, and technology/procedure/capability Modules [1].

Block 0 features Modules characterised by technologies and capabilities which have already been developed and implemented in many parts of the world today. It, therefore, features a near-term availability milestone, or Initial Operating Capability (IOC), of 2013 based on regional and state operational need. Blocks 1 through 3 are characterised by both existing and projected performance area solutions, with availability milestones beginning in 2019, 2025 and 2031 respectively.

Associated timescales are intended to depict the initial deployment targets along with the readiness of all components needed for deployment. It must be stressed that a Block's availability milestone is not the same as a deadline. Though Block 0's milestone is set at 2013, for example, it is expected that the globally harmonised implementation of its capabilities (as well as the related Standards supporting them) will be achieved over the 2013 to 2018 time frame. The same principle applies for the other Blocks and therefore provides for significant flexibility with respect to operational need, budgeting and related planning requirements.

While the traditional air navigation planning approach addresses only ANSP needs, the ASBU methodology calls for addressing regulatory as well as user requirements. The ultimate goal is to achieve an interoperable global system whereby each state has adopted (approved and deployed) only those technologies and procedures corresponding to its operational requirements [1].

2.1.2. Explaining modules and threads

Each Block is made up of distinct Modules, as shown in the previous Figure 2.1. Modules only need to be implemented if and when they satisfy an operational need in a given state, and they are supported by procedures, technologies, regulations or standards as necessary, as well as a business case.

A Module is generally made up of a grouping of elements which define required CNS upgrade components intended for communication systems, air traffic control (ATC), ground components, decision support tools for controllers, as well as for aircraft. The combination of elements selected ensures that each Module serves as a comprehensive and cohesive deployable ground-based or airborne performance capability.

A series of dependent Modules across consecutive Blocks is therefore considered to represent a coherent transition Thread in time, from basic to more advanced capability and associated performance. Modules are therefore identified by both a Block number and a Thread Acronym, as in Figure 2.2. In this illustrated example of FICE Thread, note that the Modules in each consecutive Block feature the same Thread Acronym, indicating that they belong to the same operational improvement process [1].

2.1.3. Technology roadmaps

Technology roadmaps complement the ASBU Modules by providing timelines for the technology that will support the communications, navigation and surveillance (CNS), information management (IM) and avionics requirements of the global air navigation system.

These roadmaps provide guidance for infrastructure planning (and status) by indicating on a per-technology basis, the need for and readiness of [1]:

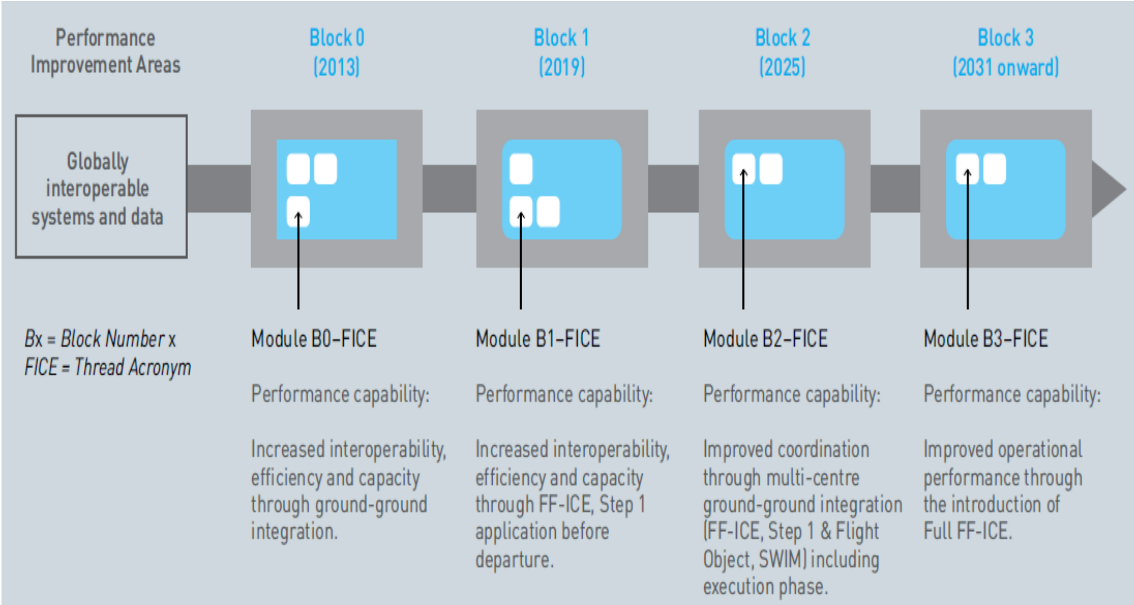

Figure 2.2: A Thread example (FICE) in one performance area [1].

1. existing infrastructure;
2. ICAO Standards and guidance material;
3. demonstrations and validations;
4. initial operational capability (IOC) of emerging technologies; and
5. global implementation.

The CNS investments represent the necessary baseline upon which the operational improvements and their associated benefits can be achieved. It must be noted that according to the achievements over the past thirty years, the typical CNS deployment cycle for large scale objectives has been of the order of 20 to 25 years (including ground deployment and aircraft forward and retrofits).

Technology roadmaps are essential for future planning of CNS/ATM areas in aviation. The example of a roadmap is presented in Figure 2.3 as a diagram which identifies the relationships between the specific Modules and associated enabling technologies and capabilities [1].

2.1.4. ATM architecture according to GANP

Part of the ICAO's GANP is the vision of future ATM architecture. It shows that technical infrastructure links to the Global Concept elements and the delivery of ATM. This infrastructure supports current operations and the fundamental change in ATM expressed in the Global Concept-trajectory based operations supported through trajectory management. These core

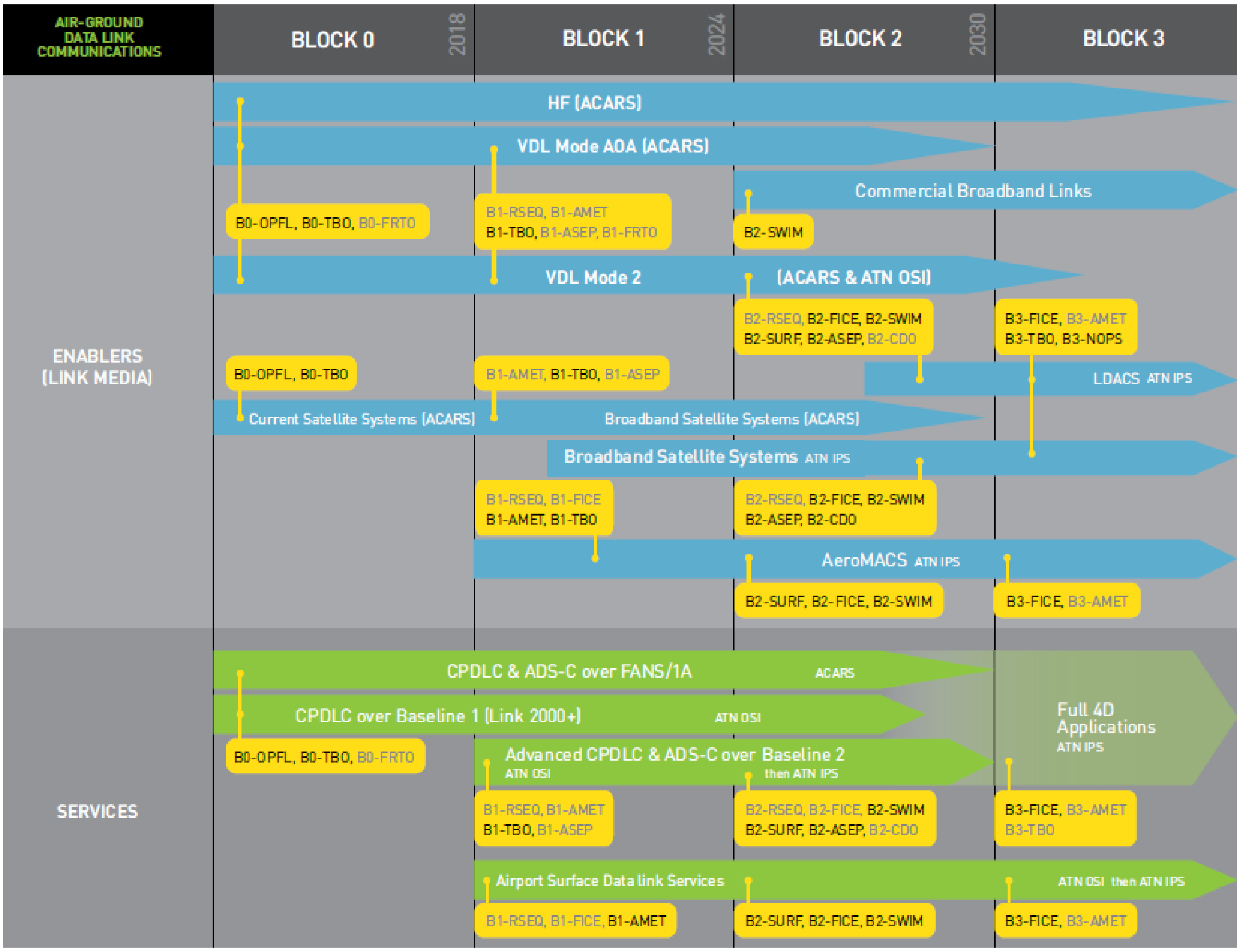

Figure 2.3: Example of the roadmap focused on communications [1].

technologies are implemented in both ground and air assets.

It can provide increased clarity on the functional requirements embedded in the ASBU Modules and should be detailed on a Module basis to delineate the various functional components impacted by each one. It should also be detailed by actors of the ATM system to identify respective responsibility as well as potential consequences on their own modernisation plan. Figure 2.4 is designed to be simple in order to illustrate [1]:

- the implications of specific functions for the different concept components;
- the performance requirements related to them;
- the elements impacted by ASBU Modules and/or Technology roadmaps of the GANP.

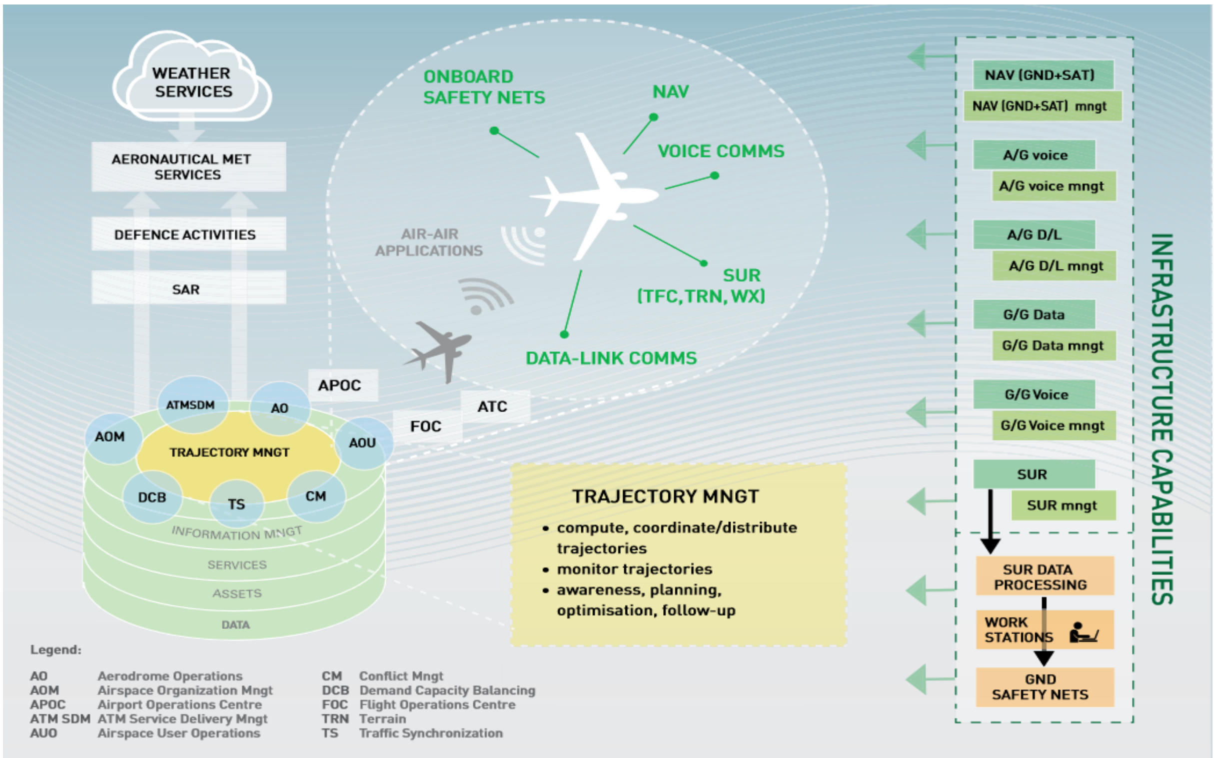

Figure 2.4: ATM Architecture according to GANP [1].

2.2. Next Generation Air Transportation System-NextGen

2.2.1. Introduction

In the United States, the Next Generation Air Transportation System (NextGen) is the complete modernisation of the National Airspace System (NAS). It is a comprehensive suite of upgrades, technologies and procedures that improve every phase of flight and enable aircraft to move more efficiently from departure to arrival. NextGen will use satellite technology to enhance navigation and surveillance, deploy digital systems for communication, and improve information management. NextGen replaces automation systems and adds more operational capabilities to the NAS. The Federal Aviation Administration (FAA) continues to validate NextGen benefits through demonstrations, trials, and initial deployment of new systems and procedures. NAS operators and users, particularly participants in demonstrations and trials, are already benefiting from NextGen. The information gained from the demonstrations provides direct measurements of the ways specific NextGen capabilities can benefit NAS stakeholders and the public [2].

The Federal Aviation Administration (FAA) continually strives to make aviation safer and smarter, deliver benefits through technology and infrastructure, and enhance global leadership [3]. The technical solutions for many NextGen capabilities have been defined, and much of the foundational infrastructure has been deployed. Research results, exchange standards, completed airspace redesign projects, and new operational and aircraft procedures have all laid the groundwork for modernising future NAS services. The modernisation initiatives must be achieved while addressing challenges such as Unmanned Aircraft Systems (UAS), cybersecurity, resiliency, and cost containment. Figure: 2.5 NextGen Enterprise Transformation provides an overview of the modernised NAS [4].

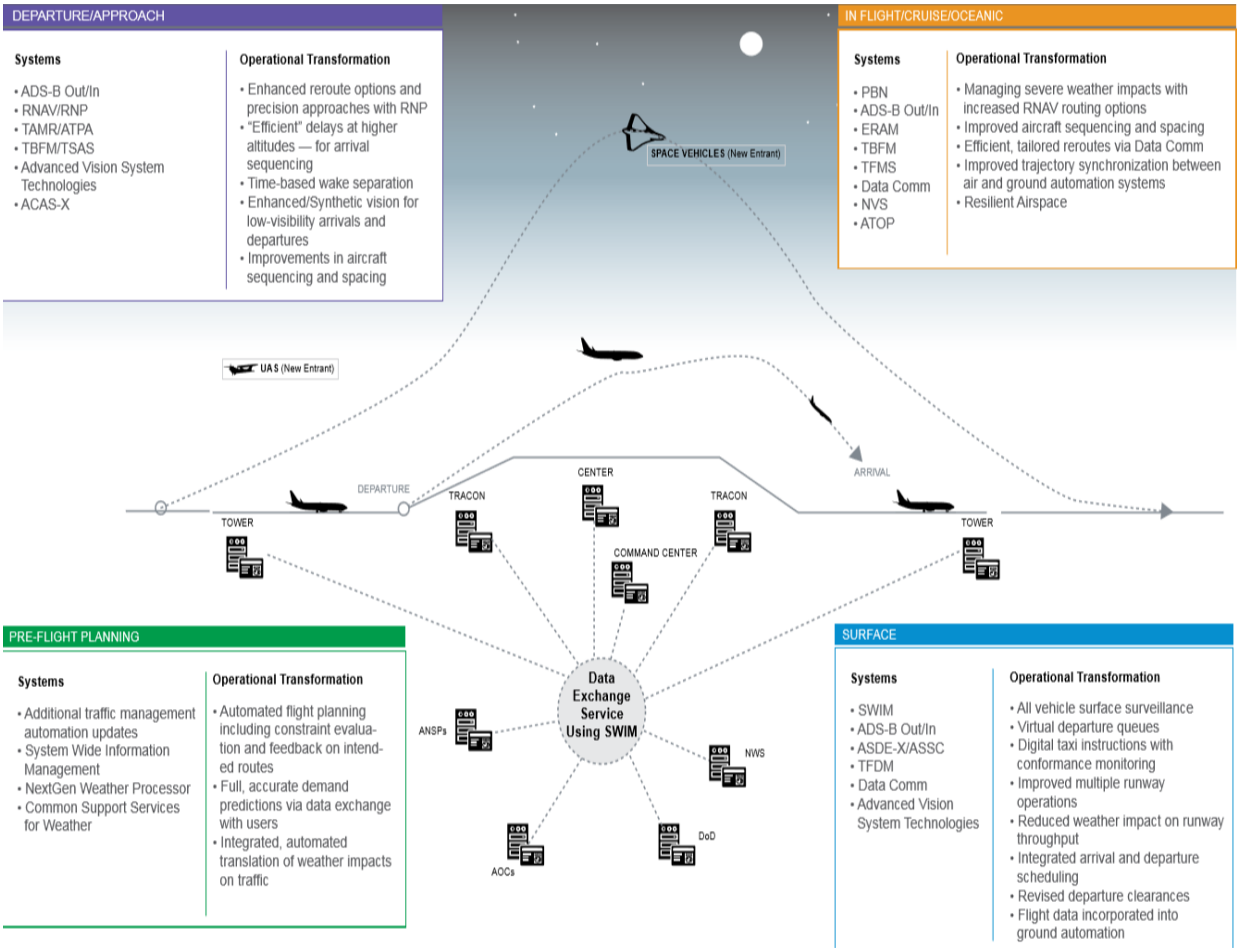

Figure 2.5: NextGen Enterprise Transformation [4].

2.2.2. NextGen elements

The movement to the next generation of aviation is being facilitated by a change to smarter, satellite-based and digital technologies and new procedures that combine to make air travel more convenient, predictable and environmentally friendly in the US's increasingly congested airspace. NextGen is expected to improve safety, reduce delays, save fuel and reduce aircraft exhaust emissions. Implementing NextGen involves complex activities ranging from concept development to deployments of capabilities in the NAS [3].

1. **Automatic Dependent Surveillance-Broadcast (ADS-B)**
   ADS-B functions with satellite rather than radar technology to more accurately observe and track air traffic. Aircraft equipped with an ADS-B Out transmitter send their position, altitude, heading, ground speed, vertical speed, call sign, and International Civil Aviation Organisation identifier to a network of ground stations that relays the information to air traffic control displays. Pilots of aircraft equipped with a receiver for optional ADS-B In also receive traffic information and can experience several other benefits. Aircraft operating in most controlled U.S. airspace must be equipped for ADS-B Out by January 1, 2020 [3].

2. **Automation**
   New, state-of-the-art computer systems have been deployed to FAA air traffic control facilities across the country. The Standard Terminal Automation Replacement System (STARS) and En-Route Automation Modernisation (ERAM) are enabling NextGen capabilities at all phases of flight [3].

3. **Data Communications (Data Comm)**
   Pilots and air traffic controllers equipped for this capability can quickly send and respond to typed electronic messages instead of talking on the radio without the risks of missed or misunderstood spoken information. Available at 62 airports before take off, Data Comm is scheduled to provide services during flight by 2020 [3].

4. **Decision Support Systems (DSS)**
   DSS provide air traffic controllers with tools to direct traffic flow as safely and efficiently as possible throughout the National Airspace System. The three systems are [3]:

   - Traffic Flow Management System is the FAA's primary system for reducing imbalances between airspace demand and capacity throughout the nation to improve strategic traffic flow.
   - Time Based Flow Management uses time instead of distance to help controllers improve en route traffic flow.
   - Terminal Flight Data Manager modernises control tower equipment and processes to improve terminal and surface traffic flow.

5. **Performance Based Navigation (PBN)**
   PBN takes advantage of GPS satellites and cutting-edge aircraft navigation equipment to

create new pathways in the sky. This allows aircraft to fly shorter, more efficient routes to their destinations while aircraft burn less fuel [3].

6. **System Wide Information Management (SWIM)**

   SWIM aggregates multiple sources of aviation data and shares it through a single access point with approved data users. SWIM increases common situational awareness and helps deliver the right information to the right systems and people at the right time for improved safety and efficiency [3].

7. **Weather**

   NextGen Weather capabilities harness massive computing power, unprecedented advances in numerical weather forecasting, translation of weather information into airspace constraints, and modernised information management services. With this powerful combination, NextGen Weather programs can provide tailored aviation weather products within the NAS, which helps controllers and operators develop reliable flight plans, make better decisions, and improve on-time performance [3].

Great progress has been made by NextGen in deploying the foundational infrastructure of the future NAS. There is still lot remaining to achieve the full realisation of the operational benefits enabled by NextGen as can be seen in Figure 2.6: Building the future [4].

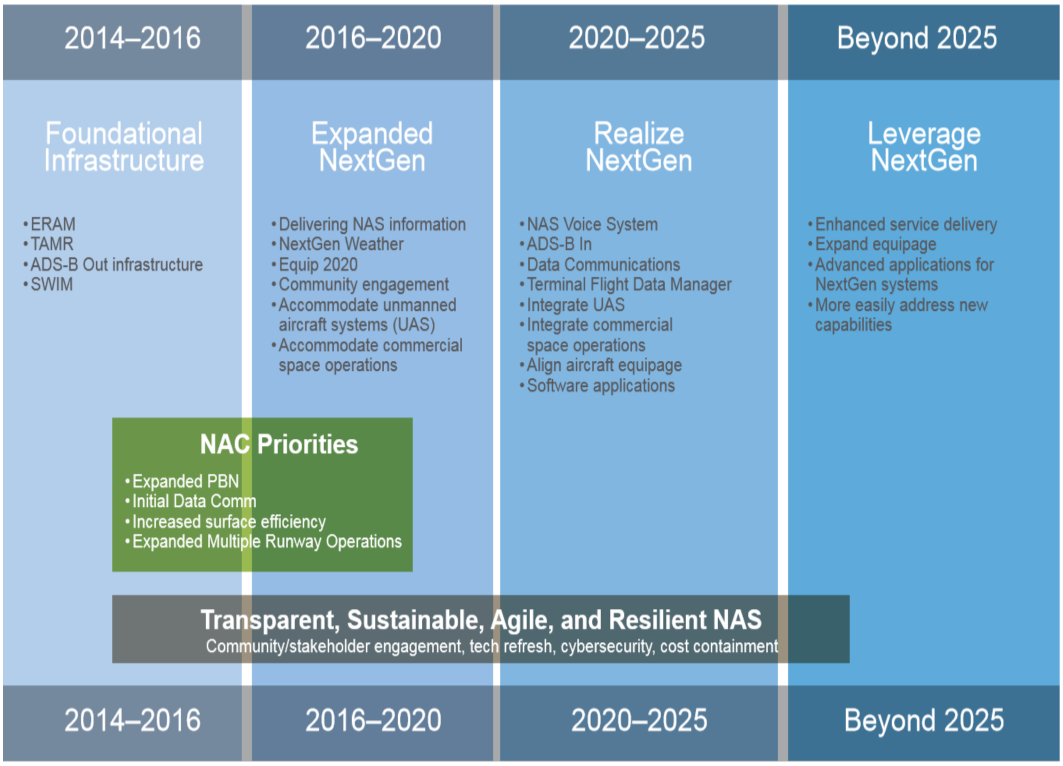

Figure 2.6: Building the future [4].

2.3. CARATS Japan

2.3.1. Introduction

The environment surrounding the country's international economic and social activities is changing dramatically and becoming more complex neighbouring Asian states are enjoying rapid economic growth, and globalisation is progressing. On the other hand, measures to counter global warming are attracting worldwide attention, and Japan is determined to address this issue positively. Japan needs to draw up and carry out a growth strategy, capitalising on its strengths to sustain its economic growth and enhance its international position. Air service is a key economic and social infrastructure that allows more people and goods to move more freely and efficiently than ever and supports Japan's growth strategy for economic and social progress and for enhancing the national living standard. It is becoming increasingly important to increase the quantity of domestic and international air service while improving its convenience and environmental friendliness. To correspond appropriately to the growth in air traffic demand as well as the diversified needs of users, through the collaboration of industry, academia and government, the future of the air navigation services have been examined from various angles and also based on global trends.

In 2010, Japan established "The long-term vision for the future air traffic systems (CARATS:

Collaborative Actions for Renovation of Air Traffic Systems)" which describes goals aimed at for 2025, directions of renovation, etc. CARATS sets goals like improvement of safety, correspondence to the growth in global air traffic demand, improvement of user-friendliness, improvement of operational efficiency, and others [5].

2.3.2. Objectives

In establishing the future air traffic systems, it is necessary to clarify the objectives (see Table 2.1, considering the needs of operators and aviation users, social and economic trends, etc. The year 2025 is the target year of the CARATS vision from 2010. In setting objectives, CARATS define specific numerical targets for the following items, taking into account the characteristics of air traffic, social situation, etc., in order to promote policies effectively, while verifying the attainment of objectives of the air traffic systems [6].

Table 2.1: Objectives of CARATS [6].

Item	**Numerical target**
Enhancing safety	Increase safety level 5times
Responding in the increase in the air traffic volume	Double the air traffic capacity in congested airspace
Improving user convenience	Improve service level (punctuality and reduction of flight time) by 10%
Increasing operational efficiency	Reduce fuel consumption per flight by 10%
Improving productivity of air traffic services	Improving productivity of air traffic services by 50% or more
Responding to environmental issues	Reduce CO2 emissions per flight by 10%
Enhancing the international presence of Japan in the aviation field	The number of international conferences in Japan, international cooperation projects etc.

The Direction of Reform to Meet the Goals was presented in 2018 by CARATS at the THIRTEENTH AIR NAVIGATION CONFERENCE in Montreal. To achieve the goals, radical reforms of the conventional ATM concept and the basis of CNS techniques must be carried out. Within CARATS framework, 8 directions were offered with a focus on the transition to TBO (Trajectory Based Operations) [5].

1. Realisation of TBO

2. Improvement of predictability

3. Ensuring information sharing for collaborative decision-making
4. Promotion of performance-based operation
5. Implementation of satellite navigation in all flight phases
6. Improvement of situational awareness on the ground and on board an aircraft
7. Maximum utilisation of human and machine capability
8. Realisation of high-density aircraft operations at busy airports and congested airspace

CARATS is also consistent with the ASBU methodology. Japan has mapped its planning to respective Block Upgrade Modules in order to ensure the near-and longer-term global interoperability of their air navigation solutions.

2.4. SIRIUS Brazil

2.4.1. Introduction

The SIRIUS program is based on the use of strategic solutions for the continuous evolution of Brazilian Air Traffic Management System to a more safety and environmentally sustainable reality. Headed by the Department of Airspace Control, the gradual implementation of the SIRIUS program will ensure to Brazil, over a time horizon of short, medium and long terms, the increase of the required operational capacity in view of the demands coming from the high air traffic growth forecast for the first decades of the 21st century, maintaining at the same time, the desired levels of operational safety [7].

2.4.2. Projects of SIRIUS

The SIRIUS program brings together a set of projects grouped in different areas (Operational Safety, Air Traffic Management, Communication, Navigation, Surveillance, Aeronautical Meteorology, Search and Rescue, Human Resources and Performance). They synthesise the strategic objectives that contribute to the modernisation of the Brazilian Airspace Control System (SISCEAB) and the consolidation of the expected benefits by society with the development of the National ATM System [7].

1. Enhancing Operational Safety Management in SISCEAB
2. Implementation of new structure to the Upper Control Areas and Flight Information Regions (UTA/FIR)

3. PBN implementation in Terminal Control Area and ATS routes optimization
4. Flexible Use of Airspace-FUA
5. Implementation of Air Traffic Flow Management-ATFM
6. Improvement of Air Navigation Services in Oil Basins-Oceanic Areas
7. Implementation of SISCEAB-CGTEC Technical Management Service
8. Ground-Ground and Air-Ground Communications Infrastructure
9. Airspace surveillance improvement
10. Improvement of Navigation Systems
11. Quality management multi-site system implementation in the provision of the meteorological and aeronautical information
12. Data Collection on Meteorological Environment

The gradual implementation of the SIRIUS program, aiming at the development of the National ATM System, is already providing benefits for members of the Aviation Community, both domestically and internationally [7].

2.5. Single European Sky ATM Research-SESAR

2.5.1. Introduction

SESAR is the technological pillar of the broader Single European Sky initiative aiming to modernise and harmonise Europe's air traffic management system. SESAR's goal is to define, develop and deploy the operational solutions with technology enablers needed to increase the performance of the European ATM system. The SESAR lifecycle is composed of three parts: definition, development, and deployment.
Established in 2007, the SESAR Joint Undertaking (SESAR JU) is responsible for coordinating and concentrating all ATM relevant research and development efforts in the European Union (EU). It is a public-private partnership between the main public stakeholders (European Union-represented by the European Commission and Eurocontrol represented by its Agency) and European aviation service and manufacturing industry. The SESAR JU is also responsible for the definition of SESAR objectives and priorities through the European ATM Master plan, which

represents the common roadmap driving ATM modernisation in Europe.
Established in 2014, the SESAR Deployment Manager (SESAR DM) is responsible for the implementation of SESAR Solutions that require synchronised deployment as part of a "Common Project" mandated by EU law. The SESAR DM plans, coordinates, synchronises, and reports on the implementation of Common Projects. Complementing these tasks, the SESAR DM is also the Data Link Services implementation Project Manager in Europe. The SESAR DM is a not-for-profit international association established under Belgian Law, composed of leading airlines, airports and air navigation service providers, selected by the European Commission to perform the SESAR DM function [2].

2.5.2. SESAR vision

As highlighted by the EU Aviation Strategy, ATM is a crucial enabler for European air transport and aviation, connecting cities and people, as well as boosting jobs and growth. Close to 30,000 flights pass through Europe daily, representing 26% of the world market, which is managed by ATM safely and sustainably. However, the landscape of European and global aviation is changing. Starting with the aircraft, which are set to become more autonomous, connected, intelligent and diverse. Moreover, then there is traffic, which is projected to grow significantly, from several thousand conventional aircraft to potentially hundreds of thousands of air vehicles (such as drones), operating in all types of airspace, including cities. Added to that are increasing demands from passengers for smart and personalised mobility options that allow them to travel seamlessly and without delay.
In support of the EU Aviation Strategy and the Single European Sky (SES), SESAR aims to deliver an ATM system for Europe that is fit for the 21st century and capable of handling the growth and diversity of traffic safely and efficiently, while improving environmental performance. This vision relies on a concept of operations underpinned by digital technologies that enable improvements at every stage of the flight (see Fig. 2.7). Put simply, the vision sees the integration of all air vehicles with higher levels of autonomy and digital connectivity coupled with more automated support for the management of the traffic. In this new paradigm, the vehicles can fly their optimum trajectories, relying on improved data sharing between vehicles and the ground infrastructure using mobile, terrestrial and satellite-based communication links. SESAR also addresses airport operational and technical system capacity and efficiency, introducing technologies such as satellite-based tools for more accurate navigation and landing, and mobile communications to improve safety on the airport surface. Meanwhile, artificial intelli-

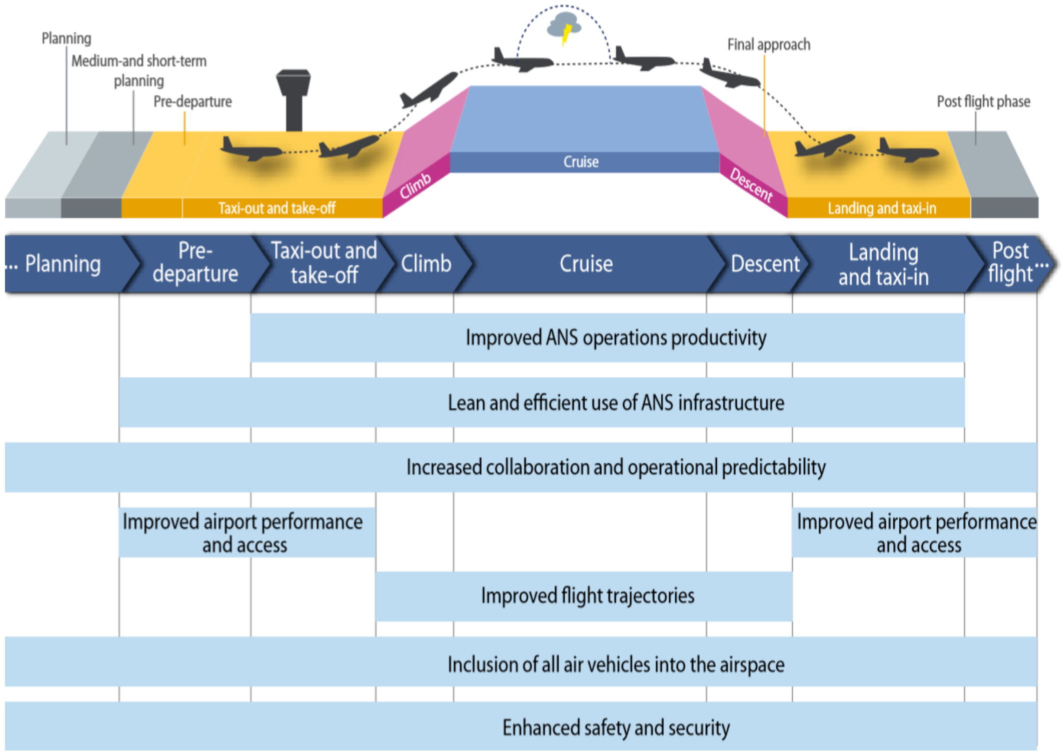

Figure 2.7: Benefits for EU citizens [9].

gence, such as big data analytics and improved data sharing through system wide information management are allowing for better flight planning, airport operations and their integration into the overall Network.

To deliver the SESAR vision, digital transformation is key whether it's through harnessing the Internet of Things, big data, artificial intelligence digital transformation and augmented reality. It is needed to embrace the technologies on offer to build an aviation ecosystem that can handle the growth and diversity of traffic efficiently, safely and with minimum environmental impact. In doing so, it will be possible to deliver the best passenger experience while also unlocking tremendous economic value for Europe [8]. This future aviation landscape is characterised in Figure 2.8.

2.5.3. European ATM Master plan

The SESAR vision is captured within the European ATM Master plan a collaboratively agreed roadmap for ATM modernisation. The Master plan is regularly updated to reflect the changing landscape to prioritise R&D activities and the solutions needed. These activities are underpinned by a concept of operations and an integrated approach to addressing different aspects of the system. In this respect, SESAR conducts transversal activities between R&D projects to ensure that the resulting solutions are interoperable and bring expected performance in terms of

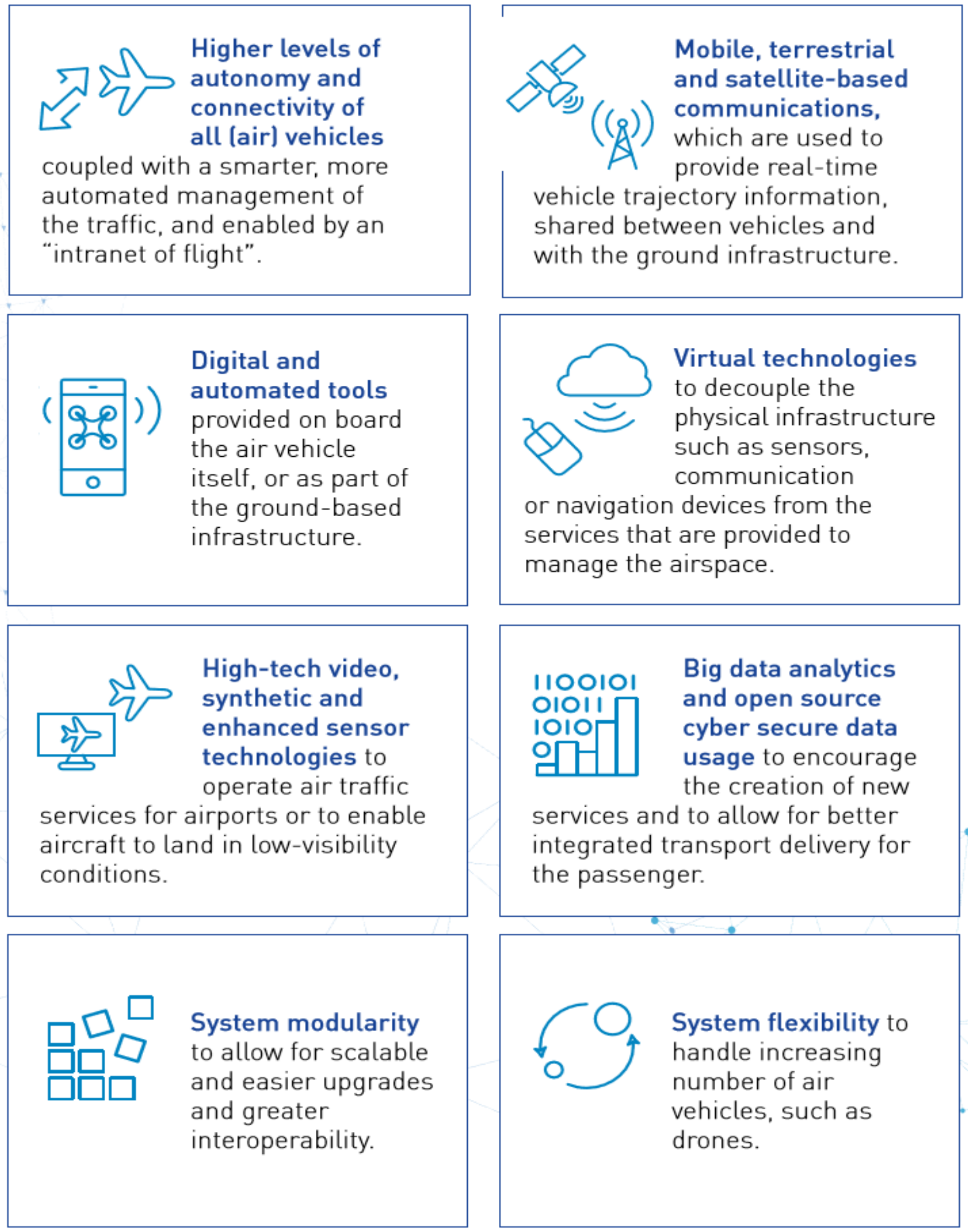

Figure 2.8: Digital SESAR objectives [8].

capacity, cost-efficiency, the environment and safety, as outlined in the European ATM Master plan. This focus on consistency and coherence across all the research projects is a unique feature of SESAR [8].

A key tool to achieving integration is the European ATM Architecture Framework (EATMA). This data repository allows experts to follow the progress as well as enabling projects to collaborate with other projects, plan modelling activity and identify gaps. Access is via the eATM portal, which captures, maintains, validates and reports on architecture-related content [8].

A standard methodology is also used to monitor and assess the performance results of solutions, measured against shared objectives in safety, security, human performance, the environment and cost benefit. This ensures all SESAR Solutions delivered throughout the SESAR programme are consistent with and contribute to EU-wide performance targets [8].

The content of the Master plan is structured in three levels, as shown in Figure 2.9, to allow stakeholders to access the information at the level of detail that is most relevant to their area of interest.

The intended readership for Level 1 is executive level stakeholders. Levels 2 and 3 of the Master plan provide more detail on the operational changes and related elements, and therefore the target audience is expert-level stakeholders.

Level 3 (Implementation View) comprises the European Single Sky Implementation (ESSIP) Plan (and Report), which is a set of commonly-agreed implementation actions. These actions, including those resulting from the other SES plans such as the SESAR Deployment Programme, help to achieve the performance targets in the areas of safety, environment, capacity and cost efficiency. In addition, Level 3 of the Master plan provides stakeholders with a basis for short-term common implementation planning [9].

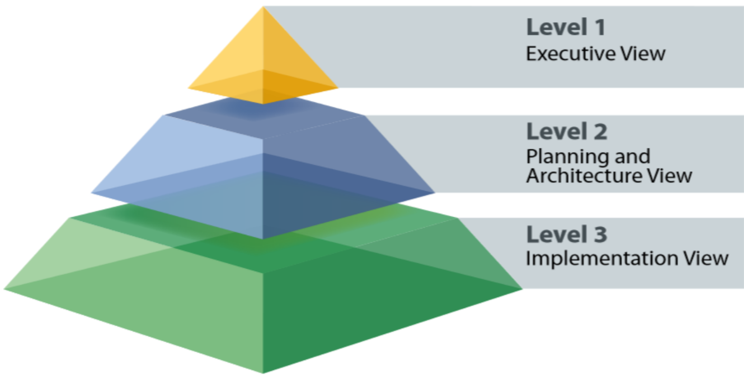

Figure 2.9: Three levels of the European ATM Master plan [9].

2.6. U.S.-EU collaboration in a global context

As two of the world's most significant aviation modernisation programmes, NextGen and SESAR have a shared interest in harmonisation as a means of ensuring interoperability. Both initiatives have identified common challenges and have adopted a performance-driven approach to modernisation. It is widely understood and accepted that the systems cannot be completely identical. However, harmonisation is necessary to [2]:

1. Ensure that flights or aircraft can operate seamlessly between systems;

2. Ensure that common standards are available where needed;

3. Minimise costs and identify synergies by sharing results and efforts.

The scope of what should be harmonised is derived from the requirements expressed by airspace users through the consultation processes of both modernisation initiatives. Before harmonised and interoperable solutions and standards are agreed, a number of collaborative steps, such as comparing and validating concepts and identifying risks, need to be taken [2].

2.6.1. Global implications

While NextGen and SESAR are the two most considerable ATM modernisation efforts in the world, parallel initiatives are being implemented in other regions. ATM modernisation is a complex task, but aviation industry stakeholders seek to harness the benefits of all of these initiatives, especially as traffic levels in civil aviation increase and new demands are placed on the system. In order to provide the highest operational and performance benefits, these modernisation initiatives must harmonise to achieve seamless operations on a global basis. ICAO is supporting the modernisation and standardisation requirements of NextGen and SESAR and recognises them as global leaders of ATM modernisation while maintaining its commitment to the broader global civil aviation community. These complex and comprehensive initiatives are, therefore, ensuring alignment with the GANP and supporting the ASBU programme [2].

3. Identification of the scientific research sections

The purpose of this chapter is to identify the most current scientific research sections in ATM. This chapter is devoted to the description of the chosen methodology used for identification. Firstly the mind mapping is introduced, subsequently, the details on the process of mind map creation and the created mind map itself are provided and lastly approaches chosen to identify the research sections are submitted. Identified results proposed in this chapter serve for subsequent comparison with the capabilities of DAT.

3.1. Mind map creation

3.1.1. Mind maps, mind mapping

Mind maps, Mind mapping, has been defined as "visual, non-linear representations of ideas and their relationships" [10]. Mind maps comprise a network of connected and related concepts. However, in mind mapping, any idea can be connected to any other. Free-form, spontaneous thinking is required when creating a mind map, and mind mapping aims to find creative associations between ideas. Thus, mind maps are principally association maps. Formal mind mapping techniques arguably began with Buzan in the 1970s. These techniques involved using lines, colours, pictures and diagrams to aid knowledge recollection [11].
The primary use of mind mapping is to create an association of ideas. However, another use is for memory retention even if the advantages in the case of mind mapping might be marginal. It is generally easier to remember a diagram than to remember a description [11]. Mind maps might be used for:

- Brainstorming
- Problem solving
- Studying and memorisation
- Planning
- Researching and consolidating information from multiple sources
- Gaining insight on complex subjects

Mind mapping has been used in a variety of disciplines including finance, economics, marketing, executive education and medicine. It is also widely used in professions such as fine art and design, advertising and public relations. In addition to these direct use cases, data retrieved from mind maps can be used to enhance several other applications; for instance, expert search systems, search engines and search [12]. The advantages of mind mapping include its "free-form" and unconstrained structure. There are no limits on the ideas and links that can be made, and there is no necessity to retain a typical structure or format. Mind mapping thus promotes creative thinking, and encourages "brainstorming" [11].

Mind mapping software can be used to organise large amounts of information, combining spatial organisation, dynamic hierarchical structuring and node folding. Software packages can extend the concept of mind-mapping by allowing individuals to map more than thoughts and ideas with information on their computers and the Internet, like spreadsheets, documents, Internet sites and images. For this thesis the XMind free mapping software was used.

3.1.2. Process of the mind map creation

Mind maps were chosen because they can represent ideas that are linked around a central theme, as well as mind maps, are considered as a natural method of organising and visualising complex data, in this case, research areas in the ATM.

To create the mind map which would enable to identify the most up-to-date research sections, the research of the plans for ATM modernisation had to be undertaken. Using the keywords (ATM modernisation, SESAR, GANP, European ATM Master plan) in the Google Search Engine, led to further exploration of the SESAR Joint Undertaking website (www.sesarju.eu). As was described in Chapter 2, SESAR is considered as the technological pillar of the broader Single European Sky initiative aiming to modernise and harmonise Europe's air traffic management system. SESAR's goal is to define, develop and deploy the operational solutions with technology enablers needed to increase the performance of the European ATM system [2]. In order to provide to a reader more profound insight into the research&development activities of SESAR, it is needed to introduce the steps of the current SESAR 2020 programme and its Innovation pipeline process.

SESAR 2020 - Is an innovative programme for researching a future of Air Traffic Management in Europe. It builds on its predecessor SESAR 1, to deliver high-performing operational and technological solutions for uptake by the aviation industry. SESAR 2020 supports the Single European Sky and EU aviation strategies vision to generate growth for European business, foster innovation and offer passengers with more connections, safer, cleaner and more affordable flights. To deliver a comprehensive programme of research, the SESAR Joint Undertaking also works closely with airspace users of all categories: professional staff organisations, regulatory and standardisation bodies and global partners. Guided by the European ATM Master plan SESAR 2020 aims to transform the European ATM into a more modular automated system that takes advantage of advances in digital and virtualisation technologies with a budget of 1.6 billion between now and 2024, SESAR 2020 will focus on developing solutions in 4 key areas, namely [16]:

1. **High-performing airport operations**, the future European ATM system relies on the full integration of airports as nodes into the network. This implies enhanced airport operations, ensuring a seamless process through collaborative decision making, in normal conditions, and through the further development of collaborative recovery procedures in adverse conditions. In this context, this feature mainly addresses the need for increased airport capacity through the enhancement of runway throughput, integrated surface management, total airport management and airport safety nets [15].

2. **Optimised network operations**, an optimised ATM network must be robust and resilient to a whole range of disruptions, including meteorological and unplanned events relying on a dynamic and collaborative mechanism. This will allow for a common, updated, consistent and accurate plan that provides reference information to all planning and executing ATM actors. This makes it possible to better consider the expected traffic demand in advance to make the required en-route capacity available. It also makes it possible to link the en-route and airport plans and capabilities to consider traffic demand from gate to gate and optimise the network capacity accordingly. This feature includes activities in the areas of advanced airspace management, advanced dynamic capacity balancing (DCB) and optimised AU operations, as well as optimised ATM network management through a fully integrated NOP and airport operations plans via system-wide information management (SWIM) [15].

3. **Advanced air traffic services**, the future European ATM system will be characterised by advanced service provision, underpinned by the development of automation tools to support controllers in routine tasks, making it possible to better address the traffic demand with increased en-route available capacity. The feature reflects this move towards further automation with activities addressing enhanced arrivals and departures, separation

management, enhanced air and ground safety nets and trajectory and performance-based free routing [15].

4. **Enabling infrastructure**, the enhancements described in the first three Key Features will be underpinned by an advanced, integrated and rationalised aviation infrastructure, providing the required technical capabilities in a resource-efficient manner. This feature will rely on enhanced integration and interfacing between aircraft and ground systems, communications, navigation and surveillance systems, SWIM, trajectory management and Common Support Services. Furthermore, the safe integration of drones in all categories of airspace [15].

The SESAR's research is categorised into three strands [13]:

1. **Exploratory research**-Explores new concepts beyond those identified in the European ATM Master plan or emerging technologies and methods: The knowledge acquired can be transferred into the SESAR industrial and demonstration activities [13].

2. **Industrial research and validation**-Assesses and validates technical and operational concepts in simulated and real operational environments according to a key performance areas. This process transforms concepts into SESAR Solutions [13].

3. **Very largescale demonstrations**-Test SESAR Solutions on a much larger scale and in real operations to prove their applicability and encourage the early take up of solutions [13].

These strands have been designed as an innovation pipeline through which ideas are transformed into tangible solutions for industrialisation.

This pipeline, clearly illustrated in Figure 3.1, starts with the EU Aviation Strategy and the Single European Sky (SES) objectives which feed into the European ATM Master plan. Exploratory research addresses both transversal topics for future ATM evolution and application-oriented research [15]. SESAR Solutions refer to new or improved operational procedures or technologies that are designed to meet the necessary operational improvements outlined in the European ATM Master plan. They are also developed in full accordance with the International Civil Aviation Organization and the Global Air Navigation Plan and therefore applicable to ATM environments worldwide [8].

SESAR 2020 and its Solutions served as the primary resource for the creation of the mind map because of its focus on current research. The mind map was set up to provide a deeper understanding of Technological enablers and Operational improvement steps that are behind each

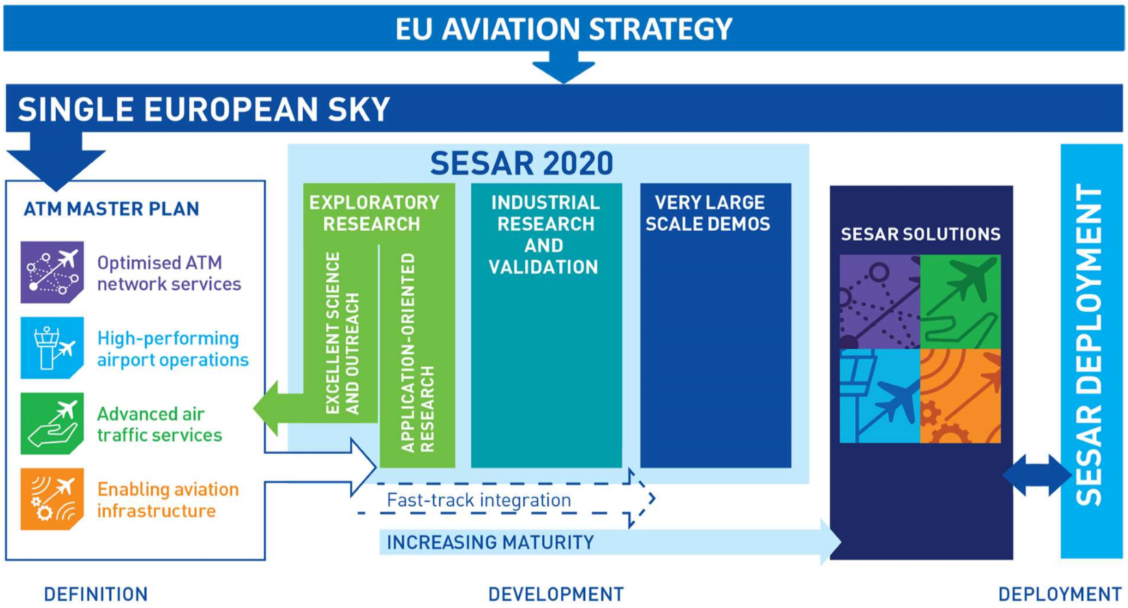

Figure 3.1: Innovation pipeline-from the EU Aviation Strategy to SESAR Solutions [14].

solution which is being developed, but mainly to help with determining which R&D sections might be further explored by the Department of Air Transport.

All Solutions are available at the European ATM Master plan website www.atmmasterplan.eu where each solution can be found under the Research& Development View in the Planning section where the solutions developed by SESAR 2020 programme are put in context and show related elements accompanied by the detailed description. With the resources described above, the mind map of SESAR 2020 Solutions was put together by using the XMind mapping software. The mind map itself is described in the following section.

3.1.3. SESAR 2020 Solutions Map

The map of SESAR 2020 Solutions was developed according to the main four key research areas of SESAR described in section 3.1.2 above. Each area contains solutions that were developed under the SESAR 2020 programme and serve as possible technological improvements of the current ATM system. The following Figure 3.2 shows delivered solutions of SESAR 2020 classified into the key research areas.

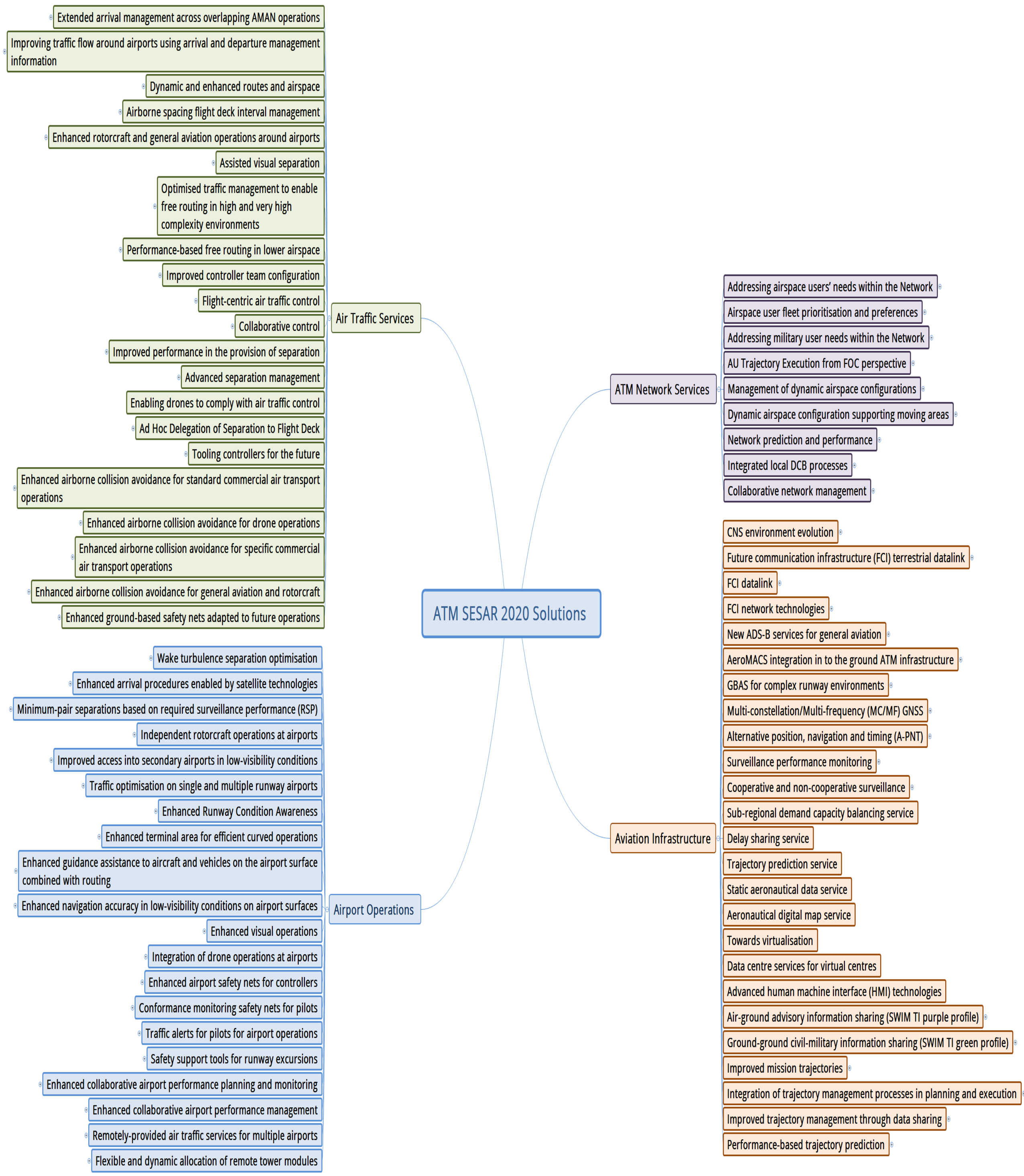

Figure 3.2: SESAR 2020 Solutions mind map.

It should be noted, however, that not every single aspect of the solution was included in the first displayed mind map as this would make the mind map very large. Instead, the cells are collapsed displaying only solutions to comprehensively present sections that are being currently researched and developed.

SESAR Solutions are the outputs from the SESAR Programme R&I activities which relate to an Operational Improvement (OI)[1] step or a small group of OI steps and its/their associated enablers (EN)[2], which have been designed, developed and validated in response to validation targets that, when implemented, will deliver business benefits to the European ATM [14]. Solutions provided in the map contain these operational improvement steps and associated enablers so a reader can easily get the notion of what is needed to enable the operation of such a solution. To demonstrate, the following Figure 3.3 shows the extended branch of CNS environment evolution solution where enablers are linked to operational improvement steps that they support. The implementation of a set of enablers allows an operational improvement step to complete. Enablers are the means to implement the change in the ATM operational environment [17]. Due to the immense size of the map, the whole map is attached in its electronic form as an interactive document that can be instrumental as a comprehensive tool to the further exploration of selected topics.

[1]OI-Operational improvements are not necessarily related exclusively to the effect of a change in technology, they can relate to procedures, working methods or routines and human factor aspects. Operational improvement is always associated with an operational benefit. Operational improvement is associated with one or more strategic objectives and is part of one or more directions of change. Operational improvement could also mean the improvement of an existing capability and/or the introduction of a new capability [17].

[2]EN-New or modified technical system/infrastructure, human factors element, procedure, standard or regulation necessary to make (or enhance) an operational improvement [17].

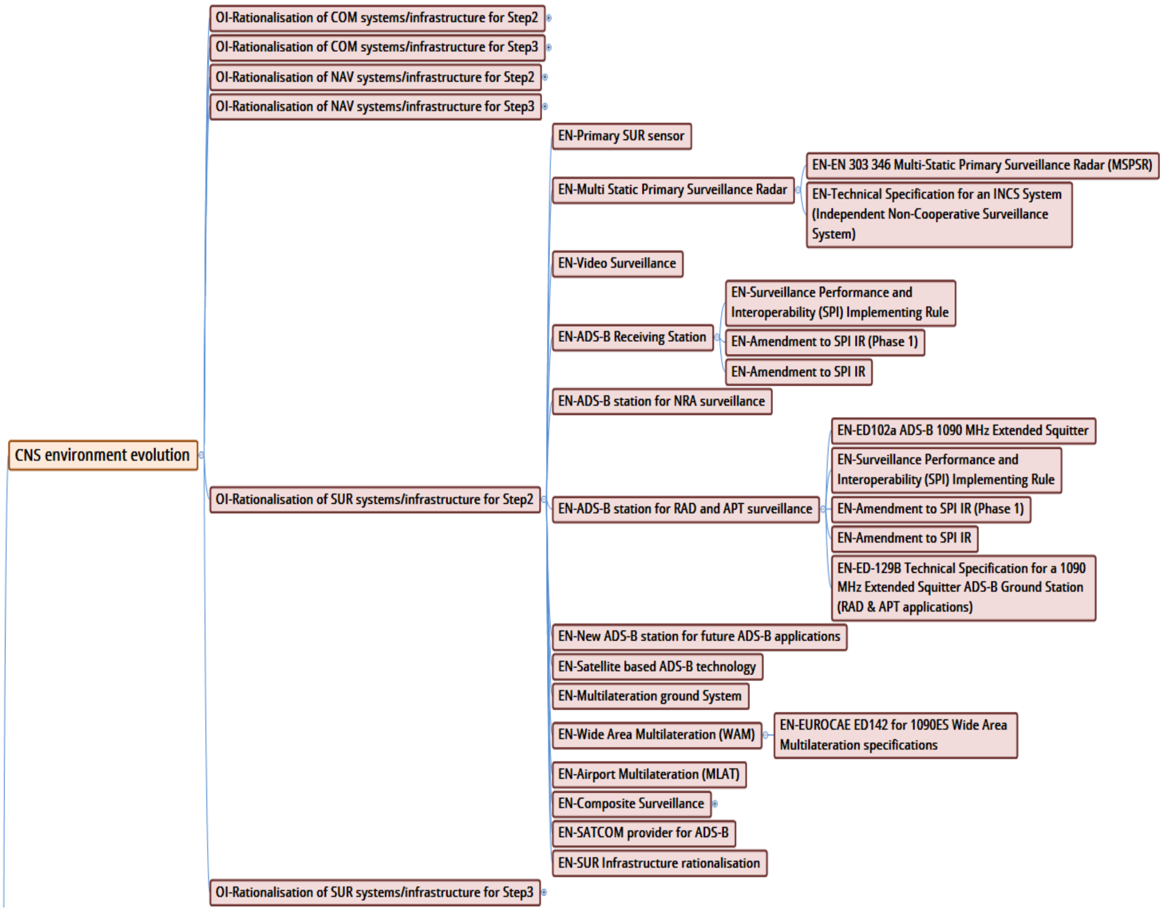

Figure 3.3: Detailed CNS environment evolution solution.

3.2. Identification of the scientific research sections for years 2019-2022

The main goal of this thesis is to identify the most up-to-date research areas. The two methods of identification are described in this section, as first, the quantitative approach based on the data obtained from the mind map. Subsequently, the qualitative method in the form of further research of the strategic documents chosen to provide more results based on the upcoming plans of SESAR.

3.2.1. Quantitative approach

An intention behind the creation of the mind map was the subsequent identification of possible research areas. As the map was being developed and become very large, it was genuinely challenging to propose which areas might need to be further researched. To determine the areas of focus, the quantitative approach was selected. As was mentioned in the section above, all solutions consist of the essential elements-the enablers which allow the operational improvement step to complete. The chosen approach intended to assess the number of enablers which occurred in the mind map repeatedly assuming that the enablers which would occur in the map the most frequently could be considered as the potential enablers for further exploration.

The quantitative approach progressed subsequently. All enablers of the SESAR 2020 Solutions map were extracted from the map into an Excel sheet. Such extracted enablers resulted in the number of 2373 cells. The Matlab software was used to quantify the number of recurrent enablers, and the following Matlab code (Fig. 3.4) enabled the quantification of the recurrent enablers by producing the Excel sheet with results. Matlab identified 269 results that appeared in the mind

```
clear all;close all;clc;
num,txt, raw]=xlsread('SESAR 2020 Solutions Statistics');
rows, cols]=size(txt);
%%
clearvars -except num txt raw rows cols;
List={};
for i = 4:rows
if isempty(List)
List{i-3,1}=txt{i,1};
else
rList, cList]=size(List);
buff=txt{i,1};
checker=0;
for j = 1:rList
if strcmp(List{j,1},buff)==1
checker=checker+1;
end
end
if checker==0
List{i-3,1}=txt{i,1};
end
end
end
List = List(~cellfun('isempty', List));
clearvars i j;
[rList, cList]=size(List);
count=[];
for i=1:rList
counter=0;
for j = 4:rows
if strcmp(List{i,1},txt{j,1})
counter=counter+1;
end
end
count(i,1)=counter;
end
List(any(count==1,2),:) = [];
count(any(count==1,2),:) = [];
%%
plot(1:length(count),count,'b');
countmax=max(count);
disp(countmax)
title('Maximum EN occurance’,'FontSize',12,'FontWeight','bold','Color','k');
xlabel('Enablers','FontSize',12,'FontWeight','bold','Color','k');
ylabel('Number of EN
occurance','FontSize',12,'FontWeight','bold','Color','k');
%%
C = num2cell(count); DatatoExp(:,1)=List;
DatatoExp(:,2)=C;
xlswrite('DataToGo',DatatoExp);
helpdlg('Check out DataToGo in Excel ;)!','Results');
```

Figure 3.4: Matlab code used for the quantification of recurrent enablers.

map more than once. To determine the number of enablers that will be later compared with the capabilities of DAT, the obtained data were sorted by the number of occurrences into the three intervals to assess the percentage ratio of the extracted data. Following the assumption that the enablers which would occur in the map the most of the time could be considered as showing the highest potential for further exploration, the data were sorted by the number of occurrences, in particular, into intervals (2-9); (10-19); (20 and more). The percentage ratio representing data classified by intervals is depicted in the pie chart in Figure 3.5. The interval of the highest number of occurrences to be exact (20 and more) equals to the 5% sample of all data that occurred in the mind map more than once. This 5% sample represents the following 13 enablers ordered in Table 3.1. Identified enablers serve for subsequent comparison with the research capabilities of DAT. As can be seen from Table 3.1, 10 of the provided results belong to

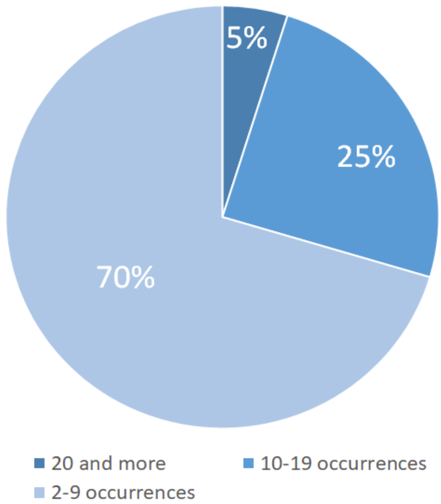

Figure 3.5: The ratio of data sorted by the number of occurrences.

category Standard or Regulation, and the rest stand for the category Systems. The description of enablers can be found at the European ATM Master plan website: www.atmmasterplan.eu where the future steps for the particular enablers are highlighted in a roadmap form. The number of occurrences was the highest for the mentioned enablers standing for legislation which is needed to implement the new operational improvement step. On the other hand, the rest of enablers belong to the category of systems and their brief description of the systems from Table 3.1 is provided below:

Table 3.1: The 13 most repeated enablers of the mind map SESAR 2020 Solutions.

Enabler	**Number of occurrences**
EN-Regulatory Provisions for Datalink Extension (DLS II), (Regulation)	70
EN-Means of Compliance for DLS II, (Regulation)	70
EN-CS in support of PCP AF3-Free Routes, (Regulation)	65
EN-New ICAO Standard for ATN/IPS, (Standard)	45
EN-Flight Information Exchange Model v4 incl. ICAO FPL 2012, Extended Flight Plan and Flight Objects elements, in accordance with SESAR FIXM Strategy, (Standard)	30
EN-MASPS and MOPS for AMS(R)S Class B, (Standard)	28
EN-MASPS and MOPS for AMS(R)S Class A, (Standard)	28
EN-Amendment to DLS IR (Phase 1), (Regulation)	23
EN-Surveillance Performance and Interoperability (SPI) Implementing Rule	23
EN-Amendment to SPI IR (Phase 1), (Regulation)	23
EN-Generate and provide MET information relevant for Airport and approach related operations, Step 2, (System)	22
EN-Provision and monitoring of real-time airport weather information, Step 2, (System)	21
EN-New remote sensing technologies supporting MET-ATM Systems for LVP Operations, (System)	21

- **EN-Generate and provide MET information relevant for Airport and approach related operations, Step 2** - The ATM-MET system is acquiring, generating, assembling and providing Meteorological (MET) information to the SWIM network in a SWIM compliant manner to support all actors in Airport and approach related operations, including rotorcraft and RPAS operations. The provided information for these types of operations is made consistent with information relevant for other operational user environments such as En-route and Network operations. Dedicated ATM-MET system capabilities will introduce new or improved meteorological observation, nowcast and forecast capabilities to support enhanced decision making. When a high level of consistency and consolidation with MET information for other operational user environments is required, the information will be made available through a system that provides this capability to consolidate and make the MET information consistent. This includes the ability to acquire, assemble and provide the relevant, ground, aircraft and space-based MET observation information [14].

- **EN-Provision and monitoring of real time airport weather information, Step 2** - ATM-MET ground based sub-system dedicated to acquire, collect, combine, provide and monitor Meteorological (MET) information from real time sensors relevant for the Airport/TMA operational environment including advanced wake turbulence applications, low visibility operations and advanced operations that are more sensitive for wind such as time-based separation and curved approaches. This ATM-MET ground based sub-system enables ATM-MET systems or ATM systems directly by providing real time MET sensor information in a SWIM compliant manner or via direct provision of the legacy/native sensor data feed [14].

- **EN-New remote sensing technologies supporting MET-ATM Systems for LVP Operations** - Novel ground based 3D-scanning sensors offer new and improved Information on low visibility conditions at the aerodrome. MET products on visibility conditions (e.g. cloud amount) representative for the aerodrome area can be derived in support of LVP Operations due to long range scanning observations [14].

Introduced enablers are related to the development of meteorological systems and the provision of information for the SWIM network and are further compared with the capabilities of DAT. The quantitative approach was one of the methods for identification of the actual R&D sections. The 13 enablers were identified according to their most frequent occurrences in the map SESAR 2020 Solutions, and this set of data serves for later discussion. Even though for this thesis the sample of 5% enablers was chosen, the SESAR 2020 Solutions map is attached as a comprehensive interactive document intending to serve as a foundation tool for future students and researchers to be aware of the problems that are solved in the framework of SESAR 2020 programme.

3.2.2. Qualitative approach

Qualitative method was added to provide another set of R&D sections complementing the quantitative approach. Particularly a method which builds on further research of the newest SESAR strategic and planning documents especially: SJU Single Programming Document 2019-2021, SESAR Solutions Catalogue 2019, European ATM Master plan and for farther future SESAR Exploratory Research document. All of these documents include information about the direction of future R&D sections that need to be addressed. For this chapter the SJU Single Programming Document provided valuable information about SESAR's plan of the projects for 2019–2022. With this in mind, this section introduces the actual Industrial research topics according to the named strategic document of SESAR. Together with the current Industrial research plan for 2019–2022, the overview also involves fundamental and applied research exploring new concepts beyond those identified in the European ATM Master plan. Exploratory Research section due to its genuinely innovative ideas could be significant for the definition of future research of DAT. Lastly, this section introduces the new European project called ENGAGE which is the SESAR's Knowledge Transfer Network. Project Engage is managed by a consortium of academia and industry to promote and facilitate the development of air traffic management research in Europe. To resume, SESAR addresses its R&D sections in main four key features Optimised ATM Network Services, Advanced Air Traffic Services, High-Performing Airport Operations, Enabling Aviation Infrastructure and the overview is structured in the same way below.

Industrial research projects for 2019–2022 according to SJU programming document [15]:

1. **Optimised ATM Network Services**
   Optimised airspace users operations
   - Enhanced integration of AU trajectory definition and network management processes
   - Mission trajectories management with integrated Dynamic Mobile Areas Type 1, 2
   - Collaborative framework managing delay constraints on arrivals

   Digital Network Management Services
   - Dynamic Airspace Configurations (DAC)
   - Enhanced Network Traffic Prediction and shared complexity representation
   - Network optimisation of multiple ATFCM time based measures
   - Digital Integrated Network Management and ATC Planning (INAP)
   - Collaborative Network Performance Management
2. **Advanced Air Traffic Services**
   Enhanced Arrival and Departures
   - Dynamic E-TMA for advanced continuous climb and descent operations and improved arrival and departure operations

- Next generation AMAN for 4D environment
- Advanced rotorcraft operations in the TMA

4D skyways

- Improved Ground Trajectory Predictions enabling future automation tools
- Improved vertical profiles through enhanced vertical clearances
- RBT revision supported by datalink and increased automation
- Trajectory Prediction Service

Separation Management and Controller Tools

- Flight-centric ATC and Improved Distribution of Separation Responsibility in ATC
- Delegation of airspace amongst ATSUs
- HMI Interaction modes for ATC centre
- Collaborative control and Multi sector planner (MSP) in en-route

IFR RPAS

- Collision avoidance for IFR RPAS
- IFR RPAS accommodation in Airspace Class A to C
- IFR RPAS integration in Airspace Class A to C

3. **High Performing Airport Operations**

Airport airside and runway throughput

- Evolution of separation minima for increased runway throughput
- Digital evolution of integrated surface management
- Advanced geometric GNSS based procedures in the TMA
- Improved access to secondary airports
- Safety support tools for avoiding runway excursions

Total airport management

- Enhanced Collaborative Airport Performance Planning and Monitoring
- Digital Collaborative Airport Performance Management

Digital technologies for Tower

- Multiple Remote Tower and Remote Tower centre
- HMI Interaction modes for Airport Tower

4. **Enabling Aviation Infrastructure**
   Integrated CNSS

   - Integrated CNS and Spectrum
   - FCI Services
   - Future Satellite Communications Data link
   - FCI Terrestrial Data Link and A-PNT enabler (L-DACS)
   - Long-term alternative Position, Navigation and Timing (A-PNT)
   - Dual Frequency/Multi Constellation DFMC GNSS/SBAS and GBAS
   - Hyper Connected ATM
   - Aircraft as an AIM/MET sensor and consumer
   - Surveillance Performance Monitoring
   - New use and evolution of Cooperative and Non-Cooperative Surveillance

   SWIM infrastructure

   - SWIM TI Purple Profile for Air/Ground Safety-Critical Information Sharing
   - SWIM TI Green profile for G/G Civil Military Information Sharing

The SESAR Exploratory Research has been briefly described in section 3.1.2. All projects that has been covered during the period 2016-2018 are ordered in Tables 3.2 and 3.3, added websites can be instrumental for a deeper insight into details and results of each project. Projects are divided in two main groups. The first group (see Table 3.2) called ATM excellent science&outreach is focused on the fundamental research in four domains, particularly: Automation, robotics and autonomy; Complexity, data science and information management covered wide, Environment and meteorology for ATM; Economics, legal and regulation. The second group (see Table 3.3) ATM application-oriented research also addressed four main areas exactly: High-performing airport operations; Advanced air traffic services; Enabling aviation infrastructure; ATM operations, architecture, performance and validation.

Table 3.2: ATM excellent science&outreach [18].

ATM excellent science&outreach	
AGENT	Adaptive self-governed aerial ecosystem by negotiated traffic (www.agent-aero.eu)
AUTOPACE	Facilitating the automation pace (www.autopace.eu)
MINIMA	Mitigating negative impacts of monitoring high levels of automation (www.minima-project.eu)
TaCo	Take control (www.tacoproject.eu)
STRESS	Human performance neurometrics toolbox for highly automated systems design (www.stressproject.eu)
BigData4ATM	Passenger-centric big data sources for socio-economic and behavioural research in ATM (www.bigdata4atm.eu)
DART	Data driven aircraft trajectory prediction research (http://dart-research.eu)
MALORCA	Machine learning of speech recognition models for controller assistance (www.malorca-project.de)
ATM4E	Air traffic management for environment (www.atm4e.eu)
BEST	Achieving the benefits of SWIM by making smart use of semantic technologies (http://project-best.eu)
PNOWWA	Probabilistic Nowcasting of Winter Weather for Airports (http://pnowwa.fmi.fi)
TBO-Met	Meteorological uncertainty management for trajectory-based operations (https://tbomet-h2020.com)
COCTA	Coordinated capacity ordering and trajectory pricing for better performing ATM (www.cocta-project.eu)
COMPAIR	Competition for Air Traffic Management (www.compair-project.eu)
Vista	Market forces trade-offs impacting European ATM performance (www.vista-eu.com)

The projects are exemplary of what can be achieved by going beyond the current horizon of knowledge in ATM and aviation by bringing scientists and industries together. Outcomes of the activities proved as the ATM is becoming more and more interdisciplinary, the current and future aviation challenges can be addressed with the application of modern tools and method-

Table 3.3: ATM application oriented research [18].

ATM application oriented research	
MOTO	The embodied remote tower (www.moto-project.eu)
RETINA	Resilient synthetic vision for advanced control tower air navigation service provision (www.retina-atm.eu)
COPTRA	Combining probable trajectories (www.coptra.eu)
OptiFrame	An optimisation framework for trajectory based operations (wp.lancs.ac.uk/optiframe)
PARTAKE	Cooperative departures for competitive ATM network service (www.partake-aero.eu)
R-WAKE	Wake vortex simulation and analysis to enhance en-route separation management in Europe (www.rwake-sesar2020.eu)
SALSA	Satellite ADS-B for lower separation minima application (www.airbus.com/salsa.html)
NAVISAS	Navigation of airborne vehicle with integrated space and atomic signals (https://navisas.tekever.com)
SAPIENT	Satellite and terrestrial architectures improving performance, security and safety in ATM
APACHE	Assessment of performance in current ATM operations and of new concepts of operations for its holistic enhancement (https://apache-sesar.barcelonatech-upc.eu)
AURORA	Advanced user-centric efficiency metrics for air traffic performance analytics (http://aurora-er.eu)
INTUIT	Interactive toolset for understanding trade-offs in ATM performance (www.intuit-sesar.eu)
PACAS	Participatory Architectural Change Management in ATM Systems (www.pacasproject.eu)

ologies from other industries. The tables of projects can be instrumental to a reader for having an awareness of the real challenges as well as innovative approaches to face such obstacles. Even though some of the listed projects have been already completed the outcomes and connected ideas can serve for further potential exploration. Subsequently, it is needed to pay attention to the 8 ongoing Exploratory Research activities which are described in full details below:

- **Engage**: *The network aims to stimulate the transfer of exploratory research results towards ATM application-oriented research. The network will establish a knowledge hub, in which members across the research community are continuously involved. This will include an observatory and undertake the role of devising and maintaining the long-term roadmap development of innovative and interdisciplinary ATM concepts beyond SESAR 2020. The knowledge hub will be the one-stop, go-to source for information in Europe. [18]*

- **EVOAtm-Evolutionary ATM. A modelling framework to assess the impact of ATM evolutions**: *The project aims to build a framework to better understand and model how architectural and design choices influence the ATM system and its behaviours, and vice versa how the expected ATM overall performances drive the design choices. The EvoATM project will model a specific part of ATM system combining the agent based paradigms with evolutionary computing. [18]*

- **ENVISION-Enhanced situational awareness through video integration with ADS-B surveillance infrastructure on airport**: *The project aims to make use of technical progress in CCTV cameras, light detection and ranging (LIDAR) technology and image processing techniques, and at taking advantage of reduced equipment costs, to provide regional and local airports safe and affordable surface movements surveillance capabilities. [18]*

- **ADAPT-Advanced prediction models for flexible trajectory based operations**: *The project proposes strategic models to predict the volume, flexibility and complexity of traffic demand taking into account both individual flights and network infrastructure (i.e. sectors and airports). The aim is to enable early flight information sharing in order to identify potential network bottlenecks and the degree of flexibility of all flights. At the tactical level, the extent to which strategically assessed pre-departure and en-route flight flexibility mitigates actual network congestion, will be evaluated. [18]*

- **GATEMAN-GNSS navigation threats management**: *Global Navigation Satellite System (GNSS), such as the Galileo constellation, will become the primary means of aircraft navigation in the mid and long term. However, GNSS signals are vulnerable to threats, especially to jamming and spoofing, which may cause the total loss of navigation. The project will research multiple measures that could be deployed on most aircraft to manage these threats, either on their own or in a collaborative fashion with other aircraft. [18]*

- **COTTON-Capacity optimisation in trajectory-based operations**: *The project aims to maximise the effectiveness of capacity management processes in trajectory-based operations taking full advantage of available trajectory information. Specifically, the projects explore the integration of demand and capacity and flight centric solutions. [18]*

- **EMPHASIS-Empowering heterogeneous aviation through cellular signals**: *The project aims to increase safety, reliability and interoperability of general aviation/rotorcraft (GA/R) operations both with commercial aviation and with emerging drones operations. These aspects are foreseen as critical elements to secure and improve airspace access for GA/R users in future airspace environment and improve operational safety of their operations. [18]*

- **Domino-Novel tools to evaluate ATM systems coupling under future deployment scenarios**: *The project will develop a set of tools, a methodology and a platform to assess the coupling of ATM systems from a flight and a passenger perspective. The platform will allow ATM system designers to gain insight on the impact of applying new mechanisms. It will provide a view of the impact of deploying solutions in different manners, e.g., harmonised vs. local/independent deployment, and information on the criticality of elements in the system and how this might be different for different stakeholders. [18]*

In response to the current ER activities, the Engage project seems to be a very helpful source for defining future research since at the core of the Engage is the definition of various thematic challenges, above all new ideas suggested by the research community, that are not yet included within the scope of an existing SESAR project. The Engage project enables participation in research by inspiring new researchers to work on the challenges within their PhD programmes or their theses. The first four thematic challenges that have been recently formulated by the research community are stated below.

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

security by design is essential: a new generation of systems architectures and applications should be explored to ensure confidentiality, cyber-resilience, fault tolerance, scalability, efficiency, flexibility and trust among data owners. Collaborative, security-related information exchange is essential to all actors in aviation. This is specially challenging in a multi-stakeholder, multi-system environment such as ATM, where confidentiality and trust are key. [19]

2. **Data-driven trajectory prediction**: *Accurate and reliable trajectory prediction (TP) is a fundamental requirement to support trajectory-based operations. Lack of advance information and the mismatch between planned and flown trajectories caused by operational uncertainties from airports, ATC interventions, and 'hidden' flight plan data (e.g., cost indexes, take-off weights) are important shortcomings of the present state of the art. New TP approaches, merging and analysing different sources of flight-relevant information, are expected to increase TP robustness and support a seamless transition between tools supporting ATFCM across the planning phases. The exploitation of historical data by means of machine learning, statistical signal processing and causal models could boost TP performance and enhance the TBO paradigm. Specific research domains include machine learning techniques, the aggregation of probabilistic predictions, and the development of tools for the identification of flow-management 'hotspots'. These could be integrated into network and trajectory planning tools, leading to enhanced TP. [19]*

3. **Efficient provision and use of meteorological information in ATM**: *The main objective of this challenge is to improve overall ATM system performance by providing better user-support tools based on improved meteorological ('met') products. The focus is on the synergy of several methods and techniques in order to better meet the needs of operational users and to support aviation safety (e.g., through creating early warning systems) and regulation-makers (e.g., moving from text-based to graphical information provision). All stakeholders may benefit from this synergy: ANSPs (e.g., sector reconfiguration and separation provision), airlines (e.g., storm avoidance), airport operators (e.g., airport management under disruptive events), and the Network Manager (e.g., demand-capacity balancing). The challenge is, therefore, to bring the following perspectives closer: (a) for meteorological/atmospheric science, the development of products tailored to ATM stakeholders' needs, which are unambiguous and easy to interpret; (b) for stakeholders, the identification of the most suitable information available and its integration into planning and decision-making processes. [19]*

4. **Novel and more effective allocation markets in ATM**: *This research explores the design of new allocation markets in ATM, taking into account real stakeholder behaviours. It focuses on designs such as auctions and 'smart' contracts for slot and trajectory allocations. It seeks to better predict the actual behaviour of stakeholders, compared with behaviours predicted by normative models, taking into account that decisions are often made in the context of uncertainty. Which mechanisms are more robust against behavioural biases and likely to reach stable and efficient solutions, equitably building on existing SESAR practices? The research will address better modelling and measurement of these effects in ATM, taking account of 'irrational' agents such as airline 'cultures'. A key objective is to contribute to the development of improved tools to better manage the allocation of resources such as slots and trajectories, and incentivising behaviour that benefits the network-for example by investigating the potential of centralised markets and 'smart' contract enablers. [19]*

To summarise, this section aimed to provide an insight into the most current challenges and problems that need to be solved in the near future together with the definition of challenges for a distant future. The comprehensive list of themes in this section is intended as a foundation document for the DAT research community.

4. Comparison of identified research parts with DAT capabilities

The Department of Air Transport has currently five laboratories at its disposal, in particular: ATM Systems Laboratory, Laboratory of Aviation Simulations, Laboratory of Human Factor and Automation in Aviation, Non-Destructive Testing (NDT) Laboratory and Aviation Safety and Security Laboratory. It has to be noted that this thesis mainly focuses on the identification of the research sections concerning the modernisation of the ATM system. Therefore it is focused primarily on the ATM systems laboratory. To compare the capabilities as well as to propose which areas might be suitable for research in the Department of Air Transport, it is first necessary to present the current research capabilities of the ATM systems laboratory. This chapter introduces ATM systems laboratory, Department projects and grants, the structured interview with the researchers working in the ATM systems field and last but not least, the comparison and intersection with identified parts for research.

4.1. ATM systems laboratory

ATM systems laboratory was established as part of the Department of Air Transport based on the need for a comprehensive platform, which would allow utilizing and developing tools aimed to address specific issues from the domain of Air Traffic Management. The laboratory is intended for research and development activities as well as support to students projects from the domain of CNS/ATM systems. It deals mainly with analyses, various types and formats of surveillance data provided by cooperative surveillance systems (SSR mode S, MLAT, ADS-B, etc.) and the possibilities for their utilization for systems operated by Air Navigation Service Providers. Adequate software tools are needed for this purpose, mostly customized to fit specific needs. The laboratory has its network of ADS-B receivers located within the Czech Republic. Cooperation established mainly with Air Navigation Services of the Czech Republic, ERA, a.s., CS SOFT a.s., allows exploitation and work with data from real systems and real air traffic operations. [20]

Main laboratory research areas and directions are: Modelling the load of RF band used by cooperative surveillance systems in the aviation (1030/1090 MHz), "Quality position indicators" analyses in ADS-B messages, Advanced methods for using radar mode S (Clustering, Dataflash applications), Possibilities for using low-cost ADS-B receivers for non-critical applications, Surveillance data provision for project dealing with the effect of condensation trails on Earth radiation balance [20].

4.2. Projects and grants

This section provides the tables of the projects in which the DAT has been involved since the year 2015, as well as currently ongoing projects. Projects undertaken on a European and National scale are ordered in Table 4.1. The mentioned European projects were both undertaken as part of the H2020 call, and National projects were all engaged in the frame of Technology Agency of the Czech Republic. Table 4.2 shows the Czech Technical University projects in from of Students Grant Competition (SGS).

Table 4.1: European projects and National projects of DAT [20].

European projects	**Period**
Capacity building for aviation stakeholders, inside and outside the EU	2015–2017
Promoting Excellence and Recognition Seal of European Aerospace Universities	2014–2016
National projects	
The Psychophysiological Condition of the Pilots and Its Influence on the Final Stage of Landing at the Airport	2019–2021
Design of Standard Scenarios for Safe Operation of Unmanned Systems	2019–2021
The value of air transport in the Czech Republic	2018–2021
Research of intelligent components of systems for collecting and evaluating safety data	2017–2019
Strategic infrastructure protective system detecting illegal acts intentionally affecting GNSS signals	2017–2019
Development of effective pilot teaching tools and methodology with an emphasis on increasing flying safety	2016–2017
Instrument Flight Procedures for Rotary Wing Aircraft	2014–2017
Research and Development of Progressive Methods for Measuring Aviation Organisations Safety Performance	2014–2017
The Utilization of Crisis Management, Risk Management, System Engineering Tools and Modern Technologies to Improve Security at International Airports in the Czech Republic	2013–2015

Table 4.2: CTU projects of DAT [20].

CTU SGS projects	**Period**
Evaluation of Pilot´s Psychophysiological State in Real Time	2019–2020
Study of Fatigue Influence on Pilot's Performance	2019–2020
Augmented Reality as a form of Pilot's Support during the Flight	2019–2020
Alternative Navigation Methods for GNSS Signal Unavailability in Aviation	2019–2020
Optimization of the Commuter Aircraft Operation Based on the Engine Monitoring System	2019–2020
Use of ADS-B Messages as a GNSS Interference Indicator	2019–2020
Conceptual Model of Integration of Safety Studies Knowledge with Safety Data from Operation	2019–2020
Model of Fatigue for Fatigue Risk Management System of Air Operator	2019
Method of calculating security performance for system-based security analysis models	2018–2019
Concept of assessing the operational efficiency of centralized security control posts at airports	2018
Evaluation of risks caused by unmanned resources in clash with man	2017–2018
Evaluation of psychophysiological state of pilots based on physiological parameters	2017–2018
Contrails in Czech airspace	2017–2018
Optimal aircraft stands configuration for international airports	2017–2018
Tool for RF Channels 1030/1090 MHz Loading Analysis	2017–2018
The Use of Sensor Networks for Passenger Security Check	2017–2018
Development of methods for implementation of evidence based training into initial professional pilot training programme	2017–2018
Safety Performance Time Series Analysis and Evaluation Model at Air Navigation Service Providers	2016–2017
The Use of Thermal Imaging Cameras During the Approach	2015–2016
Design and Testing of New Approach to Land Using GNSS for Small Uncontrolled Aerodromes	2014–2016
A Study of the Impact of Contrails on the Earth Radiative Balance	2014–2016
The Development of a Low-Cost Surveillance Solution for Noncritical Applications in the Field of General Aviation	2014–2015

4.3. Structured interview

The participants for this study were university experts and researchers working on the challenges of ATM at DAT, and structured interviews with each collected the data. The interview was chosen as a method to get a more in-depth insight into the Department's research areas as well as to get a personal opinion of researchers on the future direction of DAT research.

The questions to university researchers were sent via e-mail. After the interview was accepted the time and date of the meeting was established. All 6 interviews were recorded after the consent of the interviewee. On average, the interviews lasted about 20 min and subsequently the digital soundtrack was analysed. The interviews consisted of a total of 5 questions, and the flow of the interview proceeded from questions regarding the areas of the research at Department to more specific questions about suggested topics for future research and funding. The interview questions and the summarised outcomes are as follows:

1. **What are the main research areas at the ATM systems laboratory?**

   All interviewees responded to a question almost unanimously. The first broad area of research is the Modelling a load of RF (1030/1090) MHz band used by cooperative surveillance systems in the aviation. Specifically, the aim is to invent a tool for prediction of such SSR receivers loading. This topic is being solved in the framework of the SGS (Students Grant Competition) project called Tool for RF Channels (1030/1090) MHz Loading Analysis. As a matter of fact, by the year 2020, all states must comply with new EU legislation ensuring that 1090 MHz receivers are not overloaded. Thus this area of research is very required.

   The other mostly described topic is being solved in the scope of the national project and focuses on developing a strategic infrastructure protective system detecting illegal acts intentionally affecting GNSS signals. This project is being handled in cooperation with the Ministry of the Interior, Faculty of Electrical Engineering and GNSS Centre of Excellence. The Faculty of Electrical Engineering focuses on developing detectors, and an intensive modelling of an optimal location of such detectors is executed on the DAT. Regarding to GNSS interference, one SGS project follows this area of research by using the ADS-B Messages as a GNSS Interference Indicator.

   Another significant area of research that was mentioned by all interviewees was the development of a low-cost surveillance solution for non-critical applications in the field of general aviation based on possibilities of using low-cost ADS-B receivers and Multilateration. Similarly, the question of using the low-cost surveillance information to increase the safety of AFIS Service has been explored in the framework of the SGS project.

Next area considering the impact of aviation on the environment was utilizing the surveillance data for a project dealing with the effect of condensation trails on Earth radiation balance. This research is based on surveillance data provision accompanied by CCTV cameras so the environmental impact can be evaluated. This unique research was supported by two SGS projects dealing with this issue.

Main areas of research concerning the surveillance data utilization were mentioned. However, the interviewee admitted there might be much more to discover. Therefore the analysis of ADS-B messages shows great potential for further operational applications.

Further topics that were mentioned during the interview and which are being dealt with at the Department regarding the GNSS utilization for navigation purposes especially the design and testing of a new approach to land using GNSS for small uncontrolled aerodromes or instrument flight procedures for rotary wing aircraft using GNNS navigation. On the other hand, the opposite problem is also being solved the case of signal unavailability in the scope of the SGS project particularly: Alternative Navigation Methods for GNSS Signal Unavailability in Aviation.

Lastly discussed topic also being solved at DAT was the issue of UTM (Unmanned Traffic Management). This new and rapidly growing area opens many possibilities for future research at the Department.

2. **Are the research areas suitable for current R&D and do the areas show potential for future exploration?**

   As it has been already indicated in the first question, some of the areas explored at the Department show truly high potential for future research. All interviewees stressed the most, topics concerning the GNSS interference and load of RF band used by cooperative surveillance systems in the aviation (1030/1090) MHz. One of the respondents even suggested that the topic of GNSS interference might have potential not only for aviation but also in other areas, for instance, the road transport where the GNSS technology can be used by companies to track their drivers or to be used for collecting the toll on motorways. In such cases, the GNSS interference detecting tool could be beneficial to prevent possible illegal acts from happening. Another interviewee also emphasized the area of GNSS interference with providing an idea of the model creation supported by proper data integration which could result even in the global detection of the GNSS interference.

   As a matter of fact, air traffic is constantly growing, and the continuous development of new messages and data transmitted by aircraft is increasing, the load of (1030/1090) MHz RF channel issue becomes more and more critical. So critical that the Department currently cooperates with ANS of the Czech Republic which demands a new strategic tool to model a prediction of the loading (1030/1090) MHz RF channel in future. Even though the interviewees considered these two areas as the most important and the most critical for the near future, all areas which were mentioned in the first question show at least some potential for further exploration, that is to say, all areas explored at Department are suitable for current R&D.

3. **In your opinion, what is the potential of the ATM laboratory in the future, or what topics should be addressed and not, which are interesting and have high potential?**
The question regarding the potential of the ATM laboratory in the future was again answered almost equally saying that expertise and potential of DAT are genuinely significant. However, currently, there is a big issue with the lack of long term personnel at the Department who could work on research projects, saying that it is the main reason that keeps the advancement of DAT stagnated. The rest of the question provided a variety of answers. For instance, one respondent suggested that DAT should address areas concerning ATM procedures more, as well as to focus more on developing new strategies and procedures to improve the capacity of airspace, e.g. Sectorless ATM concept. In interviewee's opinion proposed procedural areas fit more into the concept of Faculty of Transport Sciences and DAT. There has been too much attention paid to the technical aspects of ATM. However, the primary domain of DAT should be focused more on the data analyses, the efficiency of air traffic controllers, new concepts and procedures in ATM and also operational issues. Relating to the mentioned possibilities, another significant area of concern stressed by more respondents was the use of artificial intelligence (AI), machine learning (ML) for ATM purposes. Due to the increasing digitalisation and automation in aviation, the DAT should keep up with the utilisation of the modern technologies, as well as should be able to find new ways to apply these technologies to improve the efficiency of ATM. The demand for the applications supported by sophisticated technologies is increasing, due to the enormous amount of data needed to keep everything connected. Bringing the new areas like AI and machine learning to DAT could not only help with modelling and prediction of various scenarios but also open new possibilities for future research and strengthen the profiles of graduate students so they would be able to compete on global job markets.

Moving to the areas that are exciting and high potential in the interviewees view omitting the previous AI and machine learning another frequently mentioned topic was the dilemma of drones, their integration in the airspace as well as using drones for surveillance purposes. This area shows significant potential, and due to its current expansion, the solutions concerning drones have to be brought. Said by one respondent: "This area is so new that the starting point is the same for every organisation. Therefore, we can compete and get involved in solving the UAS dilemma".

Further topic showing great potential for future exploration and was mentioned often was the Higher airspace or the area above FL 600 which is becoming a new frontier for flight. The emergence of new airspace users and operations with highly connected and automated vehicles in this higher airspace and of new commercial and state space operations will create new business and social benefits. For example, the Czech company STRATOSYST intending to send their prototypes fully functional observatories which will stay in the stratosphere and maintain the position over an extended period. Those operations, however, bring also new challenges that will have to be addressed, in particular for the aviation sector and air traffic management below FL 600 but also managing the traffic above FL 600.

Last but not least interviewees alluded to the new air traffic control simulators from Eurocontrol called ESCAPE (EUROCONTROL Simulation Capabilities and Platform for Experimentation) that will be installed at DAT in the near future. This simulator will open other possibilities for research by providing the necessary operational data. The ESCAPE simulator could also enable the simulations of the previous topic of air traffic management above FL 600 where for example the situation of getting the observatory station up to the stratosphere could be simulated, and the impact on the air traffic could be studied in depth.

4. **In your opinion, what are the financial requirements of the proposed topics and does the DAT (or FTS) have the ability to cover them?**

   Generally, the respondents stated that almost every high-quality research is financially challenging. However, DAT can solve problems more efficiently regarding finance. Research is typically founded by the public interest in the form of grants and calls ranging from the SGS to European projects. In the Czech Republic exists many opportunities for funding research concerning transportation especially the air transport. The separated question though is to consider the possible partnerships in such calls and grants for example with ANS of the Czech Republic or other even international universities. Respondents agreed that there is not a problem relating to finance; more important is the maturity of the idea and expertise coverage at the DAT followed by the proper formulation of the ideas when asking for such grants.

5. **How do you think the DAT could participate in European projects in ATM (SESAR and others)?**

   In spite of the previous answers indicating that there is a potential of some sections even on a global scale, the last question was almost unanimously followed with the negative answer. Respondents agreed there is a little chance to take part in large European projects as SESAR for the following reasons. For example, one respondent stated that DAT lacks cooperation with more prominent European universities. The universities are not aware of the research conducted in ATM systems laboratory, nor the Department has an awareness of the research in foreign universities either. Thus the necessary intersection of research that could lead to cooperation is missing. Even if the DAT could participate in European projects such as H2020, there is a lack of competence for being a leading organisation that conducts the project; hence, the partnership either with other universities or companies is inevitable.

   Even though there is a negligible chance that DAT could be a leading organisation in large European innovation projects, the same respondent also emphasized that main research areas load of RF (1030/1090) MHz channel, as well as GNSS Interference, have a high level of expertise. Therefore the DAT could offer the possible solutions to tackle the future challenges in these areas and could contribute to the European R&D.

   The topic of the effect of condensation trails on Earth's environment could be potentially the framework worth European project. Therefore the DAT intensively looks for a suitable partnership to explore the area even more.

   All interviewees cautioned about the shortage of long term personnel at the Department, seeing that as the main reason why it might be challenging to be part of such advanced projects like SESAR. Concerning the lack of workforce, another respondent suggested that due to the personnel shortage, DAT could function only as a subcontractor to the more significant organisations, for example, Air Navigation Services of the Czech Republic which is a member of B4 Consortium and taking an active part in SESAR 2020 innovation programme. Given these points, the DAT currently does not have the competence to become a full-fledged member of the SESAR 2020 innovation programme. However, DAT could participate as a member of some consortium or more likely as a possible subcontractor of a consortium member, e.g. ANS CR.

4.4. Comparison of research capabilities of DAT with identified areas

This section provides the comparison of research capabilities of DAT, in particular, the ATM systems laboratory with identified areas. The comparison is based on the results obtained from a quantitative approach and the in-depth qualitative research of current SESAR programming documents as well as documents reaching behind the scope of the newest ATM Master plan-SESAR Exploratory Research activities. Results were compared to the description of ATM systems laboratory capabilities, projects and grants in which DAT has been involved and eventually the essential information obtained after interviews with the experts working at ATM systems laboratory.

Regarding the identified topics this section aims at the possible intersection with research areas of ATM systems laboratory furthermore acknowledges the potential exploration in future.

With this in mind, each topic is presented in details, as stated in the strategic documents of SESAR. Description and steps for accomplishing the objectives are then compared with the areas of research at ATM systems laboratory supported by outcomes of the interviews which mostly enabled the evaluation of the possible intersection.

Regarding the quantitative approach, it has to be noted, that the chosen approach intended to assess the number of enablers which occurred in the mind map repeatedly-assuming that the enablers which would occur in the map the most of the time could also be considered as showing the highest potential for further exploration and the highest number of the mentioned enablers stand for legislation or standard (see Table 3.1) which are needed to implement the new operational improvement step. Even though the standards and legislative could also be potentially devised at the DAT, regulations and standardisation do not seem to be the subject for the long term evolving research concerning the modernisation of ATM systems or new operational procedures. Therefore the 10 enablers in the form of regulation and standard were found to be unsuitable for the comparison. On the other hand, the category of systems seemed to be more compelling concerning the potential for the research, nevertheless, the three enablers in form of systems namely:*EN-Generate and provide MET information relevant for Airport and* *approach related operations, Step 2; EN-Provision and monitoring of real-time airport weather information, Step 2; EN-New remote sensing technologies supporting MET-ATM Systems for LVP Operations* described in details in subsection 3.2.1 were found not intersecting any area of research conducted at ATM Laboratory. After comparing the outcomes of the interview as well as the projects where DAT has been involved, there was not found any similarity between these enablers and areas of research performed at ATM laboratory.

In the same way the Industrial research projects for 2019-2022 according to SJU programming document listed in subsection 3.2.2 were taken for consideration of possible intersections where the ATM systems laboratory could add expertise. Starting with the key area called Enabling Infrastructure which focuses more on the technical development of CNS systems; hence this area is the closest in terms of research in the ATM laboratory.

Under this category were considered following topics possibly intersecting the research capabilities at DAT:

- **Long-term alternative Position, Navigation and Timing (A-PNT)**-*The solution aims at developing A-PNT systems capable of providing better performances in comparison to the short-term solution (based on DME-DME) and support PBN/RNP operations in case of a GNSS degradation or outage. Long term A-PNT airborne solution is expected to support: RNP 1 for the Standard Instrument Departure Route (SID) or Standard Terminal Arrival Route (STAR) developed upon RNP 1 navigation specification, the airways defined with RNP 0.3 or RNP 1 constraints, and preferably RNP-APCH operations down to LNAV/VNAV minima supposing appropriate ground infrastructure. [15]*

- **Surveillance Performance Monitoring**-*The solution aims at enabling an improved performance monitoring of surveillance systems and ensuring the correct functioning of the ATM surveillance function. This applies both at the individual sensor level and ATC end-to-end level (input to the controller working position), e.g. spotting degradation trends early in the process. The solution shall consider both current and emergent surveillance techniques: WAM, ground-based and space-based ADS-B, independent non-cooperative surveillance sensors, MLAT, SMR, etc. [15]*

- **New use and evolution of Cooperative and Non-Cooperative Surveillance**-*The solution covers major improvements of cooperative and non-cooperative surveillance systems in areas such as composite surveillance (ADS-B/WAM), multi-sensor data fusion, new non-cooperative surveillance systems, secured surveillance systems and future ADS-B communications link. [15]*

All three topics were considered intersecting the research capabilities of DAT mainly for the reason that the ATM systems laboratory solves similar problems. Concerning the topic Developing A-PNT systems that aim at supporting PBN/RNP operations in case of a GNSS degradation or outage, currently, ongoing SGS project Alternative Navigation Methods for GNSS Signal Unavailability in Aviation is being solved in the Department and addressing the similar issue of GNSS degradation or outage as well.

Other mentioned topics comprise the problems connected with new use and evolution of surveillance systems. In this case, ATM laboratory which deals mainly with analyses, various types and formats of surveillance data provided by cooperative surveillance systems (SSR mode S, MLAT, ADS-B) could contribute into possible evolution and modernisation of such systems.

Further topics considered as the possible intersection belong to the category of Advanced Air Traffic Services:

- **Advanced rotorcraft operations in the TMA** - *IFR Rotorcraft operations are constrained to use same approach/departure procedures as fixed-wing aircraft, and due to their lower speed profiles, runway throughput is very often negatively impacted at busy airports. Specific rotorcraft procedures need to be defined in particular in adverse weather conditions to assist rotorcraft pilots by extending landing to degraded visual conditions. As well the development of new cost-efficient traffic surveillance systems enhancing the pilot's situation awareness and rotorcraft interoperability with GA, drones and RPAS. [15]*

- **IFR RPAS accommodation in Airspace Class A to C** - *The objective is to enable IFR RPAS operating from dedicated airfields to routinely operate in airspace classes A-C as GAT without a chase plane escort. The solution includes the development of ATC procedures, adaptations to the flight planning processes, contingency. [15]*

- **IFR RPAS integration in Airspace Class A to C** - *Solution aims at providing the technical capabilities and procedural means to allow IFR RPAS to comply with ATC instructions and the development of new procedures and tools to allow ATC to handle IFR RPAS in a cooperative environment in full integration with manned aviation. [15]*

The first suggestion regarding the Advanced rotorcraft operations in the TMA was chosen due to the recent research conducted at DAT in the scope of a national project called Instrument Flight Procedures for Rotary Wing Aircraft. Purpose of this project was HEMS operation to hospital heliports in adverse meteorological conditions. In the project framework, arrival, approach, missed approach, and departure procedures using points in space based on GNSS were constructed. As well as descend gradients, and lateral guidance was designed. [21] Gained expertise from solving the national project could be applied for R&D needs stated in the description of the Advanced rotorcraft operations in the TMA dilemma.

The number of remotely piloted aircraft systems is continuously increasing, and this will imply higher interactions with the broader ATM system. The problem of UTM was mentioned many times by respondents during the structural interview, and the integration of RPAS into the ATM is a challenge that needs to be addressed as soon as possible. Because DAT is already involved in projects regarding unmanned systems to be exact the national project Design of Standard Scenarios for Safe Operation of Unmanned Systems, the IFR RPAS topics could be taken as a proposal for further exploration at Department.

After comparing the industrial research projects planned for the years 2019-2022 the possible intersections with projects listed in Tables 3.2 and 3.3 are next to be addressed. ATM excellent science&outreach covers the fundamental research in four domains: Automation, robotics and autonomy; Complexity, data science and information management covered wide, Environment and meteorology for ATM; Economics, legal and regulation. The potential intersection was considered with projects dealing with Human Factor, specifically AUTOPACE, MINIMA, STRESS. The main interest of research of all three projects was to study the impact of automation levels on the ATCOs. For example, STRESS measured the neurophysiological signals of air traffic controllers vigilance, attention, workload, stress and type of cognitive control during the execution of operational tasks, in a simulated air traffic control environment reproducing the complexity of future airspace scenarios and associated supporting technologies [18]. Currently the Laboratory of Human Factor works on fundamental research focused mainly on pilots, especially in the framework of SGS projects: Evaluation of Pilot's Psychophysiological State in Real Time; Study of Fatigue Influence on Pilots' Performance; Augmented Reality as a form of Pilots' Support during the flight and the national project The Psychophysiological Condition of the Pilots and Its Influence on the Final Stage of Landing at the Airport. Nevertheless, by potential instalment of the new ESCAPE simulators at DAT, there might be a possibility to transition the research from the pilots also to the ATCOs. Even though this thesis is focused on the ATM systems laboratory, there is a clear intersection with the Laboratory of Human Factor research. Therefore, it has to be noted, that Human Factor research also plays a vital role for future ATM.

The rest of the projects were dealing with improving the ATM through modern approaches as artificial intelligence, robotics, autonomy, automation, machine learning, big data science and information management. The other ATM application-oriented research also explored new technologies, for instance, virtual reality for towers, augmented reality for controllers and again, machine learning as well as data processing. Any of ATM application-oriented research was not found intersecting the areas of research at DAT. Project NAVISAS seemed to be close to the research areas of ATM systems laboratory especially the Alternative Navigation Methods for GNSS Signal Unavailability in Aviation; however, their focus was primarily on developing atomic clock and atomic gyro for navigating the airborne vehicle with integrated space and atomic signals.

An increasing trend of digitalisation and automation in ATM is relevant. Coming back to the structural interview, the researchers at the DAT are aware of this new direction. However, according to the actual areas that are being solved at DAT there is not any other possible intersection with ER projects, reason being, these new technologies are not yet used at DAT for research purposes.

Next identified R&D areas that have been presented in subsection 3.2.2 are ongoing Exploratory research activities. Out of the eight introduced projects, two can be considered as intersecting the similar problems as solved at Department. For instance the Project GATEMAN (see 3.2.2) focused on proving a novel concept for integrated GNSS interferences air navigation threats management, aiming at, on the one hand, their detection and localisation and, on the other, their mitigation, either to keep GNSS navigation operative or, if that is not possible, to revert to a cost-effective alternative technology that is able to support GNSS-based approaches [22]. This project deals with a very similar issue as the national project Strategic infrastructure protective system detecting illegal acts intentionally affecting GNSS signals. By getting a more in-depth insight into the GATEMAN project can inspire further steps of research or vice versa DAT could offer its expertise in GNSS interference domain.

On the other hand project EMPHASIS (see 3.2.2) aims to increase safety and reliability of General Aviation/Rotorcrafts (GA/R) operations at low altitude as well as their interoperability with other airspace users such as commercial aviation or emerging drone operations. It is planned to achieve this through affordable CNS capabilities benefiting, among others, from existing and future mobile RF network infrastructure. The project EMPHASIS aims to develop and test the concept of such surveillance building on the ADS-B concept while addressing specific needs of low altitude airspace and GA/R community and taking into account interoperability with new users [23]. Not only the project deals with ADS-B systems, integration with drones in airspace class G, and innovative approach to certification and airworthiness, but also two participants of the project are from the Czech Republic, namely Honeywell International and Evektor. Compared to the areas of research at DAT, the project EMPHASIS intersects the areas where DAT could add its expertise and possibly establish cooperation with mentioned companies in future projects.

Lastly compared were the thematic challenges (see 3.2.2) that have been formulated by the research community within the frame of project Engage. All four themes represent the most upcoming challenges that are not included within the scope of an existing SESAR project. The thematic challenge: Vulnerabilities and global security of the CNS/ATM system are critical because 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'. As it has been mention many times during this section, DAT actively participates in addressing the issues of detecting illegal acts intentionally affecting GNSS signals, therefore, could also add its expertise and be involved in this thematic challenge.

Even though the project Engage is yet to be fully developed, regular attention should be paid for potential active participation in the next thematic challenges. Project Engage might serve for future PhD students as a platform providing calls and inspiration for the most up-to-date research in ATM.

5. Summary and recommendations

The principal purpose of this thesis has been to identify the most current R&D areas concerning the modernisation of ATM and compare them with the research capabilities of DAT. The first part of the thesis was devoted to the overview of the programmes of leading global organisations working on solving future challenges in ATM.

The identification of the most was undertaken with the help of the mind map of the SESAR 2020 Solutions which served as a basis for subsequent quantitative method, and the qualitative method was based on in-depth research of the SJU strategic planning documents. A quantitative approach was conducted by extracting the data from the mind map and succeeding evaluation assuming that the highest number of technological enablers which occurred in the map the most frequently could also be considered as showing the highest potential for further exploration. This method provided the list of the topics that were compared; however, any similarities with research areas carried out at Department were not found whatsoever.

The second, qualitative approach provided a list of topics and projects considered to be the primary research areas for years 2019–2022 as well as the new areas of exploratory research aiming at tackling further future challenges. After comparing the qualitative results, themes that somewhat corresponded to the research conducted at DAT were determined. Areas and projects intersecting the research areas of DAT are listed in section 4.4.

Besides, the structured interview conducted with experts working on the modernisation of ATM at DAT was another valuable source of information regarding the future potential areas for research. Based on the interviewee's opinion the following areas were proposed as a possible direction for future exploration: Artificial intelligence and Machine learning to further advancement of current research areas, Unmanned Traffic Management and Drones integration as well as Higher airspace operations above FL 600. These areas are very actual and show high potential for long term future research where the DAT could consider its participation.

Furthermore, the detailed R&D needs of the identified themes are provided in Annex A.1 describing which steps are necessary to progress in research.

In conclusion, it can be said that the research conducted at DAT show considerable potential for the future. In particular, the area dealing with GNSS interference detection. Detecting and mitigating GNSS interference is becoming more and more critical in order to prevent possible cyber attacks while navigating aircraft. Moreover, the second area showing high potential for further research is a load of (1030/1090) MHz RF channel issue. As the air traffic is continuously growing, and the continuous development of new messages and data transmitted by aircraft is increasing, a load of (1030/1090) MHz RF channel problem becomes more and more important. These two areas being solved at Department correspond with research themes that are very actual and being addressed on the European scale. Hence, DAT could get involved with its high level of expertise in more significant European projects.

Besides the mentioned areas, the new ESCAPE simulator that is going to be installed at the DAT will offer new possibilities and expand the areas for research at the DAT. Therefore it can be said that the potential for future research is genuinely significant.

Taking all the research mentioned in the thesis into account, I would like to propose the following recommendations for DAT:

- The Department of Air Transport should focus more on research in areas concerning ATM procedures, on developing new concepts and procedures to improve the capacity of airspace, e.g. Flight-Centric ATM concept, delegation of airspace amongst ATSUs etc., as well as on addressing the operational issues.

- The DAT should be able to react to the increasing digitalisation and automation in aviation and put more emphasis on computer sciences. Bringing the new areas like AI and Machine learning to DAT could not only help with modelling and prediction of various scenarios but also open new possibilities for future research.

- The DAT could consider cooperation with Faculty of Electrical Engineering (FEE) in terms of coordination of the project-oriented study so that the new concepts and operational procedures would be suggested at DAT and the technical aspects enabling the new concepts could be carried out by FEE.

- The DAT should deepen cooperation with companies actively working on SESAR projects (e.g. Air Navigation Services of the Czech Republic, ERA a.s, CS SOFT a.s., Honeywell International) so the DAT could add its expertise as a possible subcontractor. DAT should also try to find a partnership among European universities conducting the related research.

- The DAT should actively follow the project ENGAGE, which defines new thematic challenges that are not yet included in the scope of any SESAR project and are defined by the research community. ENGAGE will also become the knowledge hub a single European point of entry for ATM knowledge. Hence, it can be useful as a source of information about the most current research as well as the possibility for PhD to participate in European ATM projects.

Complementary to the recommendations, two roadmaps concerning the similar areas to the research at DAT and the possible cooperation for future are suggested in appendices A.1, A.2. Roadmaps attempted to propose a view to the year 2025.

The thesis outcomes might serve as the foundation of themes intended for the next potential research activities at the Department of Air Transport at the Czech Technical University in Prague as well as an inspiration for the students to come who might explore the topics more in-depth in terms of their theses.

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6. List of abbreviations

ADS-B	Automatic dependent surveillance-broadcast
AFIS	Aerodrome flight information service
AIM	Aeronautical information management
AMAN	Arrival manager
AMS(R)S	Aeronautical mobile-satellite (R) service
ANSP	Air navigation services provider
A-PNT	Long-term alternative position, navigation and timing
ASBU	Aviation system block upgrades
ATC	Air traffic control
ATCO	Air traffic controller
ATFCM	Air traffic flow and capacity management
ATFM	Air traffic flow management
ATM	Air traffic management
ATN	Aeronautical telecommunication network
ATSU	Air traffic services unit
AU	Airspace user
CARATS	Collaborative actions for renovation of air traffic systems
CNS	Communication, navigation and surveillance
CTU	Czech Technical University
DAC	Dynamic airspace configurations
DAT	Department of Air Transport
DataComm	Data communications
DCB	Dynamic capacity balancing

DFMC	Dual frequency/multi constellation
DLS	Datalink services
DME	Distance measuring equipment
DSS	Decision support systems
EATMA	European ATM architecture framework
EGNOS	European Geostationary Navigation Overlay Service
EN	Technological enabler
ER	Exploratory research
ERAM	En-Route automation modernisation
ESCAPE	EUROCONTROL simulation capabilities and platform for experimentation
ESSIP	European Single Sky implementation
EU	European Union
FAA	Federal Aviation Administration
FANS	Future air navigation system
FEE	Faculty of Electrical Engineering
FF-ICE	Flight and flow information for a collaborative environment
FIR	Flight information region
FIXM	Flight information exchange model
FTS	Faculty of Transportation Sciences
FUA	Flexible use of airspace
GA	General aviation
GA/R	General aviation/rotorcraft
GANP	Global air navigation plan
GAT	General air traffic

GATMOC	Global air traffic management operational concept
GBAS	Ground based augmentation system
GNSS	Global navigation satellite system
GPIs	Global plan initiatives
GPS	Global positioning system
HEMS	Helicopter emergency medical services
HMI	Human machine interface
ICAO	International Civil Aviation Organization
IFR	Instrument flight rules
IM	Information management
INAP	Integrated network management and ATC planning
IOC	Initial operating capability
IPS	Internet protocol suite
LDACS	L-band digital aeronautical communications system
LIDAR	Light detection and ranging technology
LNAV	Lateral navigation
LTE	Long term evolution
LVP	Low visibility procedures
MASPS	Minimum aviation system performance standards
MET	Meteorological information
MLAT	Multilateration
MOPS	Minimum operational performance standards
MSP	Multi sector planner
NAS	National airspace system

NDT	Non-destructive testing
NextGen	Next Generation Air Transportation System
NOP	Network operation portal
NPA	Non-precision approach
OI	Operational improvements
PBN	Performance based navigation
PCP	Pilot common project
PIRGs	Planning and implementation regional groups
R&D	Research and development
R&I	Research and industrialisation
RAIM	Receiver autonomous integrity monitoring
RBT	Reference business trajectories
RF	Radio frequency
RNP	Required navigation performance
RPAS	Remotely piloted aircraft systems
SBAS	Satellite based augmentation system
SES	Single European Sky
SESAR	Single European Sky ATM Research
SESAR DM	Single European Sky ATM Research Deployment Manager
SESAR JU	Single European Sky ATM Research Joint Undertaking
SGS	Students grant competition
SID	Standard instrument departure
SISCEAB	Brazilian Airspace Control System
SJU	SESAR Joint Undertaking

SMR	Surface movement radar
SPI	Surveillance performance and interoperability
SSR	Secondary surveillance radar
STARS	Standard terminal automation replacement system
SWIM	System wide information management
TBO	Trajectory based operations
TMA	Terminal control area
TP	Trajectory prediction
UAS	Unmanned aircraft systems
UTA	Upper control area
UTM	Unmanned traffic management
VNAV	Vertical navigation
WAM	Wide area multilateration

A. Roadmaps and R&D needs

A.1. Roadmap and R&D needs for new identified research areas

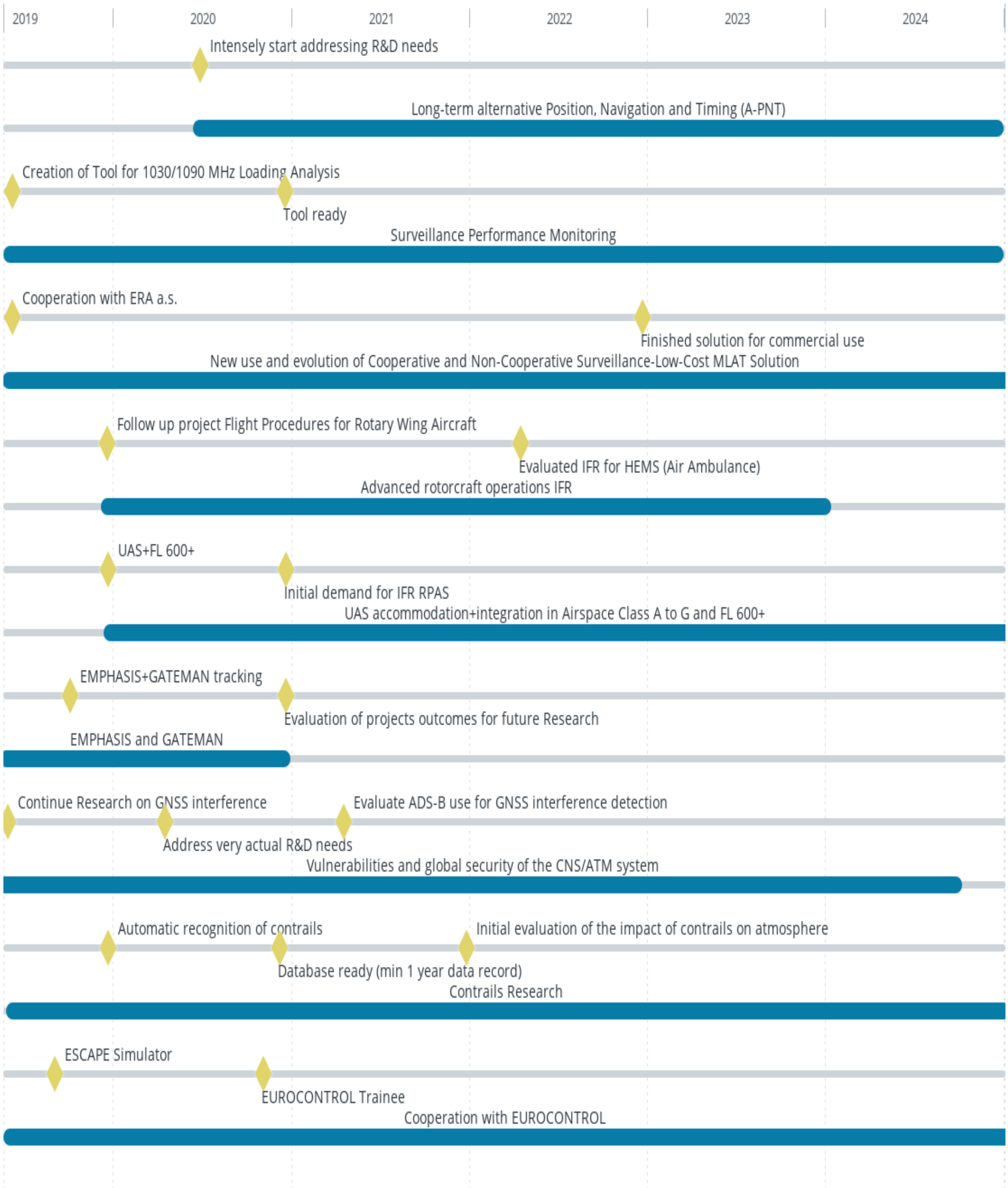

Figure A.1: Roadmap of new areas for future exploration.

Long-term alternative Position, Navigation and Timing (A-PNT) [24]

- The A-PNT requirements for all phases of flight including navigation reversion modes and increased autonomy aspects; The technologies selected from the candidates considered in Wave 1 (initial candidate technologies include Multi-DME solution and RAIM algorithm, Enhanced DME, L-DACS-NAV, Mode N, Inertial, including data fusion of these different sources) with regards to the required navigation performance and integrity.
- Long term A-PNT will be based on a new system/technology that has not yet been defined or standardized by ICAO, which may require major changes of the existing ground and on-board systems.
- The identification and detailed description of long-term selected candidate new technologies for rotorcraft, RPAS, GA, etc. (e.g. terrain or visual based navigation, Inertial) to provide on airborne side additional enabling capabilities which will allow for all phases of flight in degraded conditions in constrained environment, providing more efficient usage of airspace.
- CNS synergies should be taken advantage of to the maximum extent possible. Further work is also necessary on operational requirements in order to confirm the required navigation performance (i.e. accuracy, continuity, integrity), especially in light of multi-constellation GNSS capabilities and the ability to mitigate associated residual system vulnerabilities.

Surveillance Performance Monitoring [24]

- Consideration of both current and emergent surveillance techniques: WAM, ground-based and space-based ADS-B, independent non-cooperative surveillance sensors (INCS, including MSPSR), MLAT, SMR, etc.
- The adaptation of the methods and tools from Wave 1 to take into account the evolution of the emerging standards, and the completion of the work performed in Wave 1.

Evolution of Cooperative and Non-Cooperative Surveillance [24]

- Adding new capabilities (e.g. security screening and reporting methods for cooperative sensors) into existing technologies such as multi-sensor trackers, ADS-B systems, WAM/MLAT systems, video trackers; the MLAT component of the sensor shall receive video plot measurements and uses this data to solve ambiguities. This is a new composite type consisting of cooperative and non-cooperative surveillance.

- The evolution of ADS-B datalink and the exchange of data between sensors, and composite surveillance to improve sensor ambiguity resolution performance; range (via active interrogation) and range difference (via passive interrogation) measurements from Mode-S (without azimuth measurements) to update the track state (position, velocity, etc.).
- Security aspects beyond classical cybersecurity mitigating growing threat levels.

Advanced rotorcraft operations in the TMA [24]

- Flight management and guidance for improved lateral navigation in approach via RNP 0.1.
- Use of SBAS/EGNOS technology to support low RNP (e.g. RNP 0.1) flight procedures.
- The effective and efficient integration of rotorcraft in the ATM environment by providing pilots with new cost efficient traffic surveillance systems enhancing their situation awareness as well as interoperability with GA, drones and RPAS.
- The effective and efficient integration of rotorcraft in the ATM environment by providing pilots with new cost efficient traffic surveillance systems enhancing their situation awareness as well as interoperability with GA, drones and RPAS.
- The development of operational concepts based on new technologies to support integrated rotorcraft and drones/RPAS flight operations.

IFR RPAS integration in Airspace Class A to C [24]

- Development of operational requirements and technological solutions for communication between ATC and IFR RPAS.
- Investigation of the potential need for modified separation minima between IFR RPAS and between manned aircraft and IFR RPAS, including both wake and radar separation minima.
- Assessment of navigation performance requirements for RPAS, including assessment of the ability of an RPAS to execute existing published procedures, and development of new procedures if necessary.

IFR RPAS accommodation in Airspace Class A to C [24]

- The identification of the initial accommodation needs for the 2021-2025 producing a well-defined characterization of the accommodation needs both in terms of platforms and in terms of flights/missions that they will want to conduct in European airspace.
- To allow the accommodation to be possible in the short term, the accommodation solution shall consider that the communications between the remote pilot and ATC will be via the same voice radio frequency used by ATC to communicate with manned aircraft in the same sector (directly or through a relay).
- The research must establish the potential impact on ATC capacity and efficiency of accommodating IFR RPAS, and produce guidance material for managing this impact.
- Development or adaptation of ATCO procedures and support tools for handling IFR RPAS.

Higher Airspace Operations FL600+ [25]

- Differentiation between very diverse FL600+ Ops, in particular differentiate the Space Operations (incl. launch, re-entry), from other higher airspace Ops.
- Regulation&certification for the (air)craft, operation, crew licensing.
- In the longer term, dynamic management of airspace adapted to the systems performance, reliability, safety, manoeuvrability, predictability and flight profile.
- Minimise impact on ANSP and other Lower and Upper Airspace stakeholders.
- Position reporting and surveillance.
- Live communication with pilot/commander.

Vulnerabilities&global security of the CNS/ATM system [19]

- 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.
- 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.
- Deeper study on the security analysis of aviation specific protocol implementations (vulnerabilities, trust, software library).

- Requirement of updating software and firmware of IT components in order to fix security vulnerabilities of any critical infrastructure.

GATEMAN [22]

- Novel concept for integrated GNSS RFI (both jamming and spoofing) air navigation threats management, aiming at, on the one hand, their detection and localisation and, on the other, their mitigation.
- Innovative threats management approach will allow, either to keep GNSS navigation operative or, if that is not possible, to revert to an alternative PNT technology that is able to support GNSS-based approaches (at least NPA procedures), and that is cost effective because it minimises the need for the deployment of additional ground infrastructure to be funded by ANPS or other aviation stakeholder.
- Management of those GNSS threats would be based on existing aircraft equipment (with minor modifications), with an optional operational mode in which a ground facility would be involved.

EMPHASIS [23]

- Investigating use of existing (3G/LTE) and future (5G) cellular infrastructure to provide low-cost data-link for low-altitude GA/R operations, provide additional source of positional data (multilateration).
- Enhance accuracy, integrity, and availability of GNSS navigation by considering:systems (INS), 4G/5G positioning, autonomous integrity monitoring (eRAIM).
- Surveillance building on the ADS-B concept while addressing specific needs of low altitude airspace and of GA/R community and taking into account interoperability with new users.
- Explore possible approaches how to achieve the objectives of the certification process through alternative means benefiting from evolution of today's flight environment and taking into account specificities of low altitude operations.

A.2. Roadmap for future cooperation with organisations

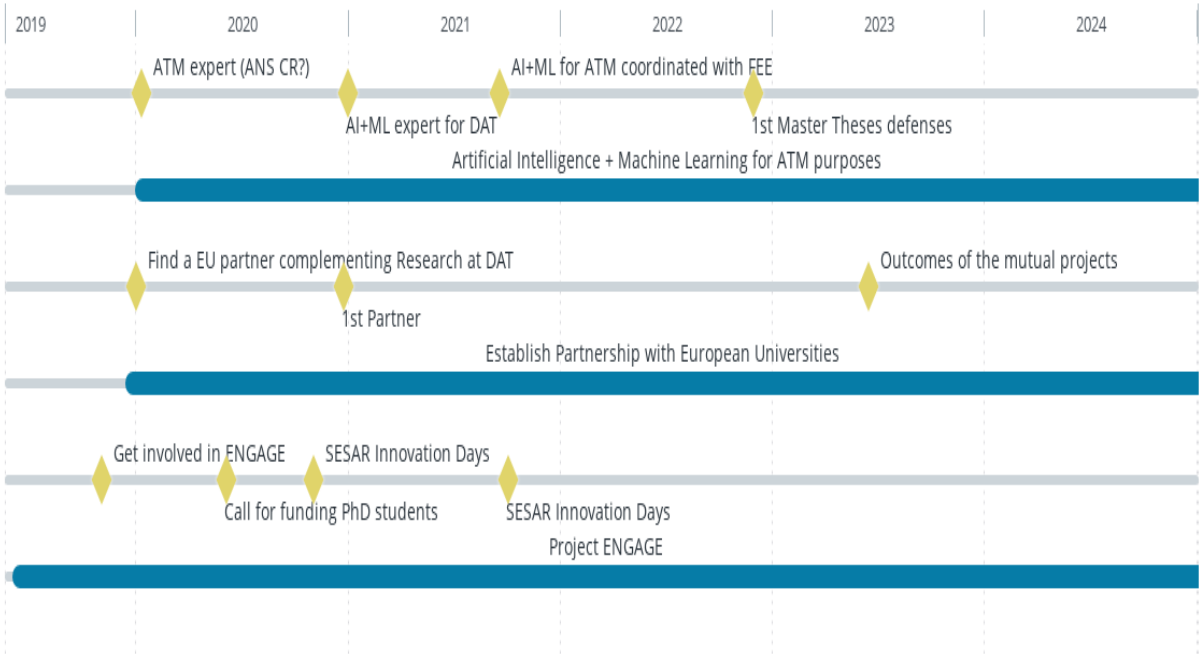

Figure A.2: Roadmap for future cooperation with organisations.