Strategic Research and Innovation Agenda

Digital European Sky

DRAFT

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Digital European Sky

As part of Horizon Europe - the next EU research and innovation programme (2021-2027) - the European Commission plans to establish a number of partnerships in several strategic industrial areas, including for air traffic management (ATM). The future partnership for 'Integrated ATM' will build on the success and the momentum generated by the SESAR Joint Undertaking to deliver the Digital European Sky, making air transport smarter, more sustainable, connected and accessible to all civil and military airspace users, including new entrants.

Complementing the European ATM Master Plan 2020 and the High-Level Partnership Proposal, this Strategic Research and Innovation Agenda (SRIA) details the research and innovation roadmaps to achieve the Digital European Sky, matching the ambitions of the "European Green Deal" and the "Europe fit for the digital age" initiative. The priorities outlined in this SRIA will also be critical for a post-COVID-19 recovery, enabling aviation to become more scalable, resilient, economically sustainable, environmentally efficient and predictable.

Table of contents

List of figures

List of roadmaps

1 Introduction

1.1 Purpose of this strategic research and innovation agenda

This document describes the Strategic Research and Innovation Agenda (SRIA) to support the delivery of the Digital European Sky. Together with the proposal for an "Integrated ATM" partnership [14], these documents present the scope and approach to further modernisation of Europe's air traffic management (ATM) capabilities and U-space within the second pillar of Horizon Europe – Global Challenges and European Industrial Competitiveness, more specifically within the Climate, Energy and Mobility cluster, but also linked to the Digital, Energy and Space cluster [13].

This SRIA presents the strategic research and innovation (R&I) roadmaps for the years 2021 to 2027 in order to deliver on the implementation of the European ATM Master Plan 2020 edition longer-term vision for the strategic phases C (defragmentation of European Sky through virtualisation) and D (Digital European Sky) up to 2040+ (see [1]).

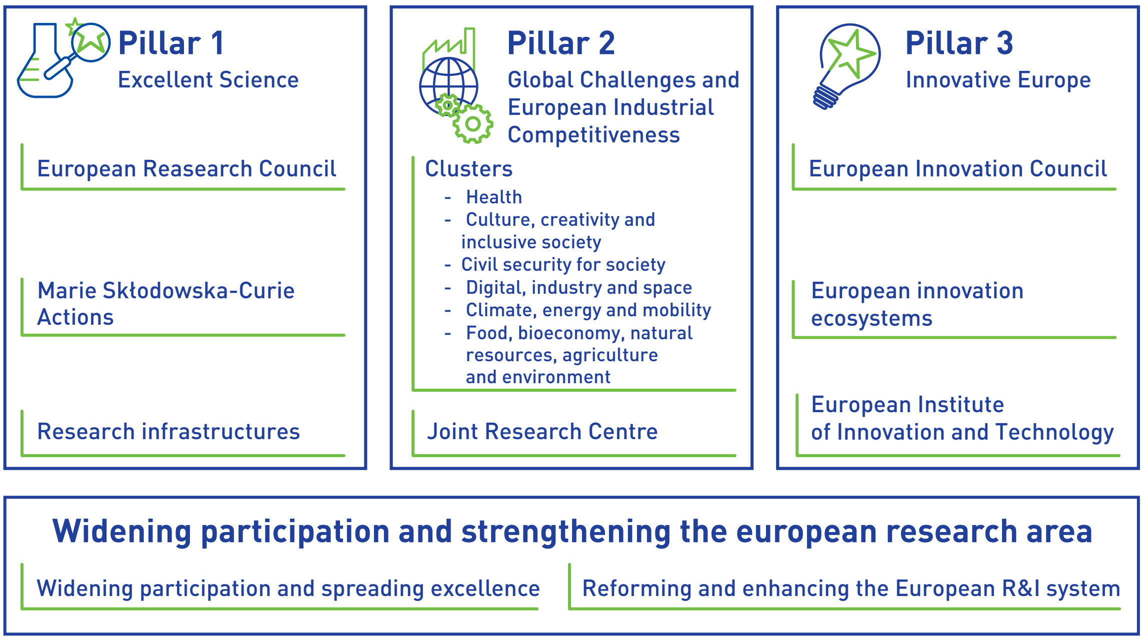
The SRIA roadmaps correspond to a number of smart and measurable objectives for this time period and the associated output measurements in line with the metrics of the European ATM Master Plan performance chapter. The SRIA shows the various benefits resulting from the implementation of the R&I.

Once the new partnership has been agreed, this SRIA will have to be adopted by its members as the starting point for its work programme.

1.2 Basis and timeline

The SRIA has been developed by the members of the existing SESAR Joint Undertaking (SESAR JU), under the coordination of the SESAR Master Planning project (PJ20). It has undergone extensive consultation of the full range of ATM stake-

Figure 1 – HORIZON EUROPE



Source: Orientations towards the first Strategic Plan implementing the research and innovation framework programme Horizon Europe [13] holders including those interested in high-level operations and the use of unmanned aircraft systems (drones) and U-space.

The SRIA and the roadmaps included herein have been developed on the basis of the following main inputs:

- The recently adopted European ATM Master Plan edition 2020 [1]
- The Airspace Architecture Study (AAS) [11] and its AAS Transition Plan [12]
- The European Green Deal [3]
- Flightpath 2050 [4], and the ACARE SRIA 2017 Update Volume 1 and 2 [15]
- Commission Implementing Regulation (EU) 2019/123 of 24 January 2019 laying down detailed rules for the implementation of air traffic management (ATM) network functions and repealing Commission Regulation (EU) No 677/2011 [19]
- Inputs from current SESAR JU and candidate future partnership members and other stakeholders, taking into account the specific ATM priorities in light of the COVID-19 crisis.
- A comprehensive consultation cycle using the Eurocontrol Civil-Military Stakeholder Committee and involving U-space stakeholders. Furthermore, through the SESAR JU, the Master Planning Committee's advice was included.

This SRIA benefits from the recent update of the European ATM Master Plan 2020 edition, which has been developed through a comprehensive process involving all relevant ATM stakeholder groups and consultations at expert and political level. This made it possible to minimise the development time of this SRIA while ensuring a broad stakeholder buy-in.

1.3 Organisation of this document

This document is organised into three main chapters.

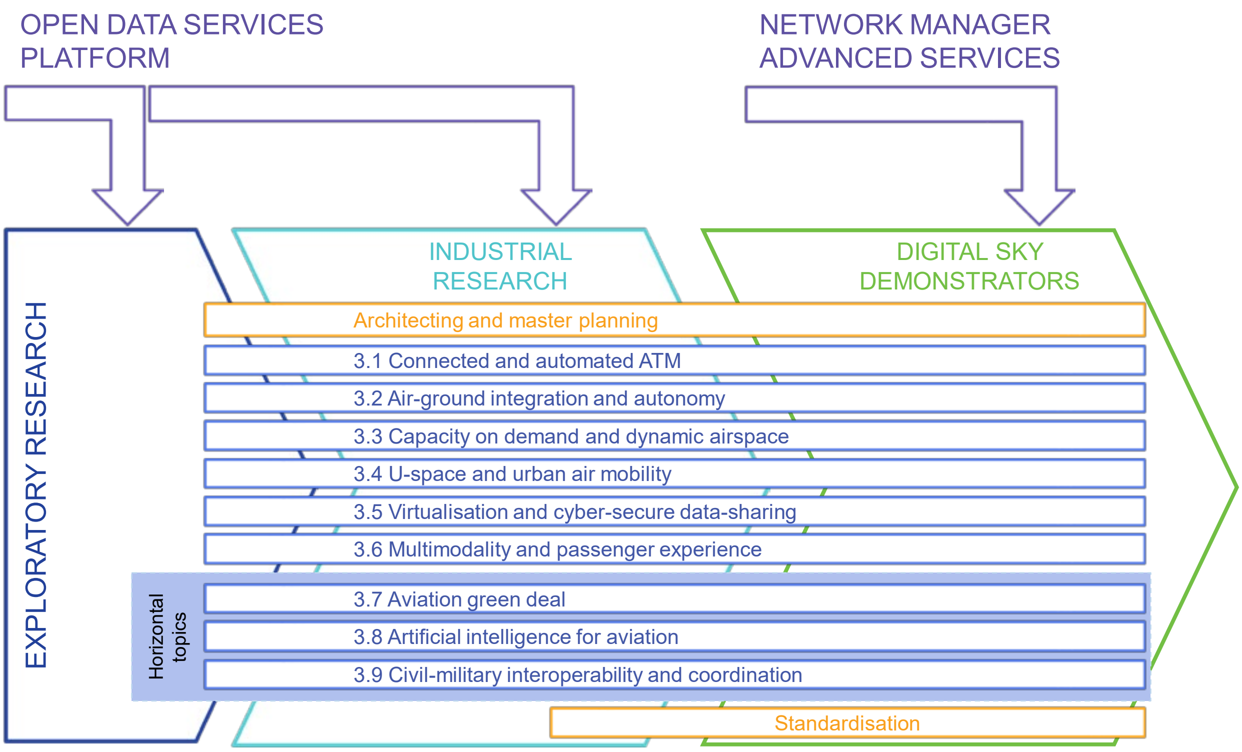
Chapter 2 captures the Vision for the Digital European Sky as already expressed in the recently published ATM Master Plan 2020 edition [1]. It also explains what the main challenges are in realising this Vision that need to be addressed by implementing this SRIA. It furthermore explains what the main instruments for implementing the SRIA are and how synergies will be created with other Horizon Europe and ATM-related initiatives.

Chapter 3 presents the research and innovation roadmaps of this SRIA. As can be seen in Figure 2., nine flagship activities have been identified that generally span the three instruments, namely exploratory research, industrial research and Digital Sky demonstrators, which will be developed (see 2.3). While there are many interdependencies between these flagship activities, three flagships, the so-called **horizontal topics**, connect with all the others. The roadmaps for each of the flagship activities are elaborated in the corresponding section of chapter 3.

To implement the SRIA a number of further activities need to be carried out that are not further detailed in this SRIA. These are the so-called transversal activities of architecting and master planning, and standardisation.

Chapter 4 concludes the document by presenting information on the expected economic impact of implementing this SRIA and the foreseen impact on key ATM performance areas.

Figure 2 – OVERVIEW OF FLAGSHIP ACTIVITIES AND INSTRUMENTS



Source: SESAR Joint Undertaking

2 Vision, impact and synergies

2.1. Vision leading to the Digital European Sky

Air traffic management (ATM) provides an essential service for aviation. While the essence of ATM is and will always remain, to ensure the safe and orderly execution of all flights, it needs to do so in the most environmentally friendly and cost-efficient way. The provision of this ATM service follows the demand for air transport and other airborne operations. Since the beginning of aviation, this demand has generally seen a pattern of growth. Whenever ATM is not able to deliver capacity where and when it is needed, measures are taken to continue to ensure safety, causing rapid increases in delays and thereby a deterioration in environmental efficiency, cost efficiency and the achievement of airspace user needs.

While the vision expressed in this SRIA is based on forecast growth in air traffic demand, not only from traditional air transport and other types of users (such as state aircraft, business aviation and general aviation), but also from all types of drones, it is also strongly motivated by the need to make ATM much more dynamic in predicting and responding to spatial and temporal fluctuations in air traffic activity. Such fluctuations may arise from events such as significant weather, system failure, volcanic activity, or from pandemic disease outbreaks similar to SARS and COVID-19.

Moreover, European policies are seeking significantly reduced emissions from aviation and in this context, accommodating growth for the sake of growth is not the objective. Aviation growth does not originate from within, but has external market considerations that cannot be overlooked. Indeed, as air traffic will have increased significantly year on year, the same would hold true for environmental and health impacts. This is why, with the delivery of the Digital European Sky, positive action will be taken to contribute to an irreversible shift to low- and ultimately no-emission mobility; the challenge is zero inefficiencies due to ATM by 2040. This means not only eliminating inefficiencies in the current system but also in the design and execution of the future ATM and U-space architecture.. This commitment shown by aviation stakeholders confirms SESAR's long-standing efforts to ensure that European citizens can travel by air while leaving a minimal environmental footprint.

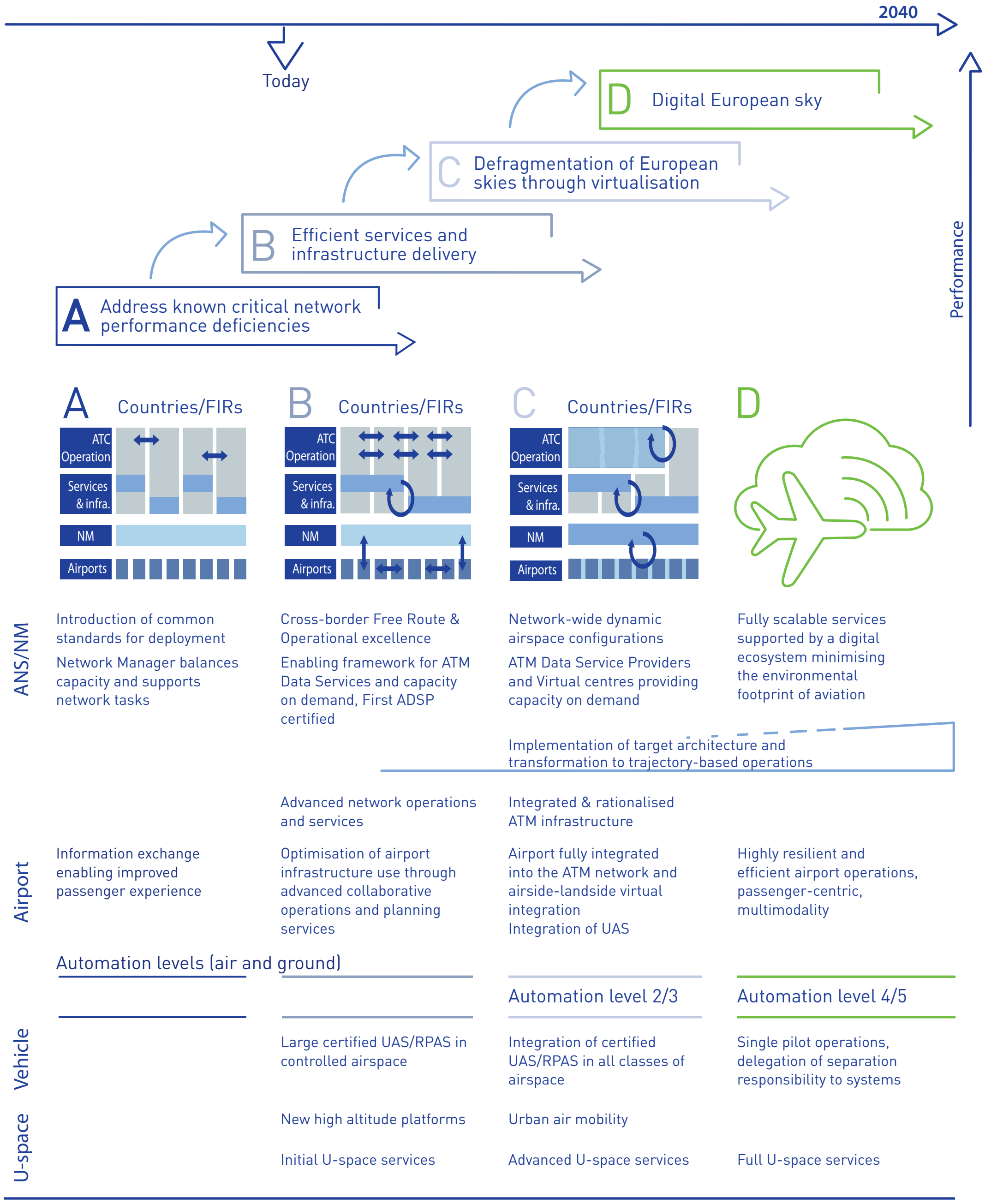
The vision pursued through this SRIA is to make the Digital European Sky the most efficient and most environmentally friendly sky to fly in.

With this goal in mind, ATM and aviation will evolve to an integrated digital ecosystem characterised by distributed data services. Leveraging digital technologies to transform the sector, the aim is to deliver a fully scalable ATM system for manned and unmanned aviation that is even safer than today's, and, based on higher air-ground integration.

The European Network Manager will be capable of building a very accurate picture of the predicted traffic situation well in advance, using advanced analytics. In order to resolve capacity bottlenecks and optimise the services offered, in coordination with the stakeholders involved, the airspace and service provision allocation will be dynamically reconfigured and capacity will be made available where and when it is needed by activating capacity-on-demand services.

In the densest areas of Europe, however, demand for ATM has started to exceed the capacity that current best operational concepts are able to provide. When the research of this strategic agenda starts to be implemented in operations, the core ATM system will reach a high degree of automation in the air and on

Figure 3 – VISION OF THE EUROPEAN ATM MASTER PLAN – PHASES A TO D



Source: ATM Master Plan 2020 edition

the ground. The developments addressed in this SRIA will advance the level of automation at least to Level 4 (High automation) for some of the tasks (as depicted in Figure 4). Airborne operations will experience a rise in complexity due to a combination of factors, including advanced flight profiles, digital communication and new airborne capabilities. Artificial intelligence (AI) will offer significant support to pilots, controllers and other ATM personnel, substantially optimising operations and alleviating the workload generated under these conditions through digital assistants and the automation of trajectory management.

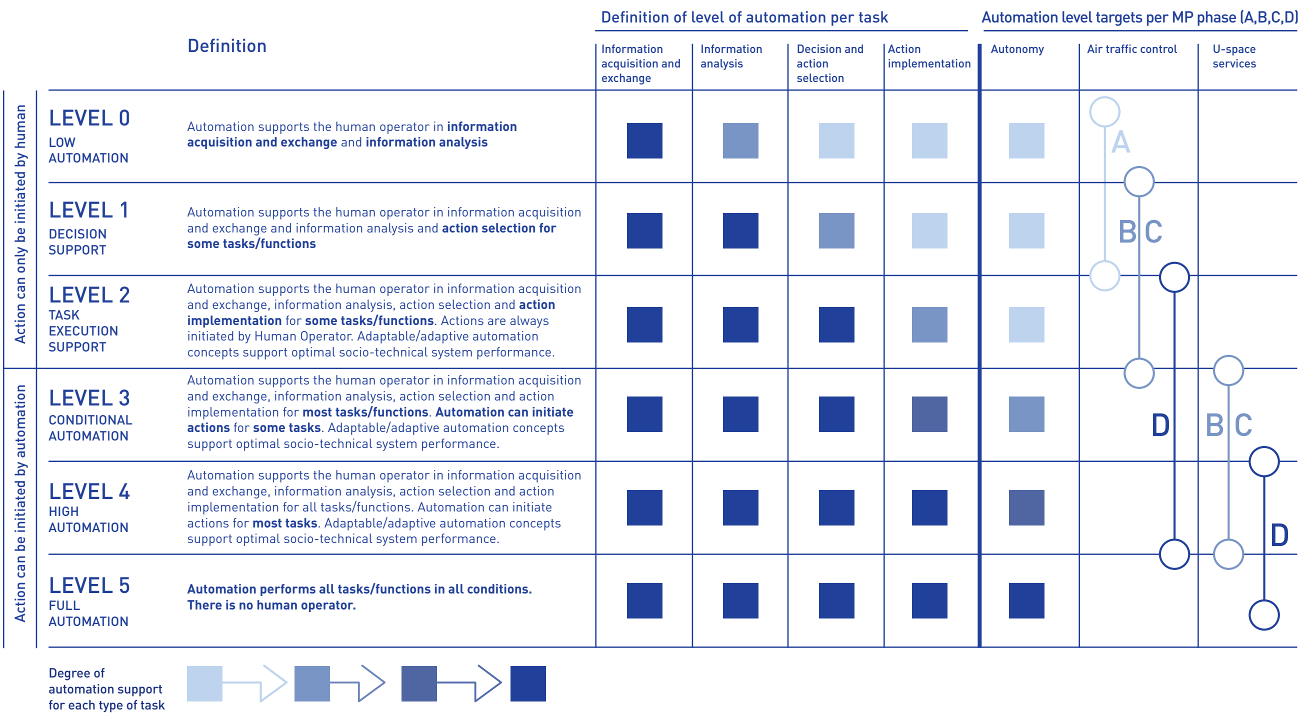
Pilots are likely to count on digital assistants powered by AI to automatically negotiate with the ground and manage any trajectory changes. On the ground, in a joint cognitive system, air traffic controllers (ATCOs) could delegate a large portion of their tasks to machines that can help to provide operational services in a safe and efficient manner. The system will propose the best possible options to the human (flows, sequences, separation assurance, etc.) and will solve complex trajectory situations using machine-to-machine communication with air vehicles. Automation and AI will also support air traffic safety electronics personnel (ATSEP) in identifying proactively any potential technical degradations or cyber-security breaches, in attaining a distributed-system-wide situational awareness, and in sustaining service delivery availability at the required quality levels of accuracy and integrity as well as continuity of service. Also staff working on managing airport operations will benefit from advanced levels of automation and AI, based on full and integrated information exchange with other actors.

As a result, all demands would be accommodated with little or no delays while maximising the use of the available resources.

The full implementation of ATM virtualisation will enable the complete decoupling of ATM service provision from the physical location of the personnel and equipment. This will rely on hyper-connectivity between all stakeholders (ground-ground and air-ground) via high-bandwidth, low-latency fixed and mobile networks (including satellite). Highly automated systems with numerous actors will interact with each other seamlessly. The scaling up and down of system performance will happen in quasi-real time, as and when required. In this context, multiple options can be envisaged for the reorganisation of ATM services in relation to geography and flight execution (e.g. collaboration between ATM service providers across Europe and seamless end-to-end ATM service provision). The evolution to this future ATM architecture is depicted in Figure 5..

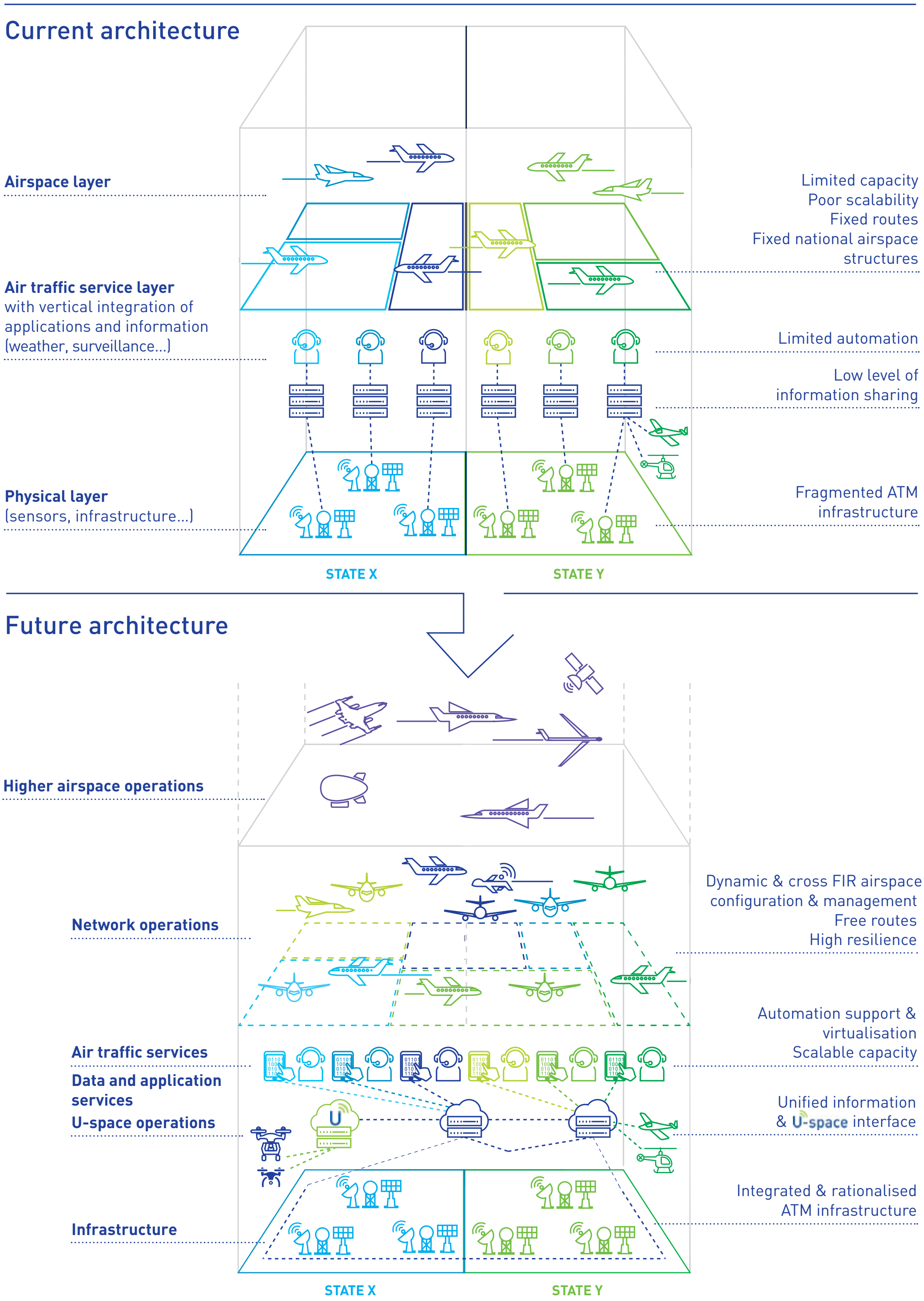
Smart airports, fully part of the ATM network, from smaller regional ones with easy local access, to big hubs, will become a reality. They are nodes of an integrated European multimodal transport network, placing the service to the connected passenger at the centre of their business. At the same time these smart airports will contribute to further improving turn-around and take-off time compliance, addressing one of the main factors of uncertainty in making trajectory predictions. Advanced virtual technologies will enable all-weather operations and reduced delays.

Figure 4 – LEVELS OF AUTOMATION



Source: ATM Master Plan 2020 edition

Figure 5 – EVOLUTION OF THE EUROPEAN SKY



Source: Updated from ATM Master Plan 2020 edition

This will offer passengers (and goods) a seamless and hassle-free travel experience, combining different modes of transport for door-to-door journeys. Many types of airspace users will be part of, or provide services to providers of mobility as a service. Autonomous vertical take-off and landing-capable air taxis, fuelled by zero-carbon power sources, such as sustainable aviation fuels (SAF), green electricity or hydrogen, will provide new ways to connect airports with populated areas. For example, urban air mobility will feature flying taxis operating at low and very low levels in urban and suburban areas, evolving from today's helicopters towards increasingly autonomous operations using alternative propulsion and new vehicle designs. Urban air mobility will be one of the most demanding use cases for U-space, while in addition to passenger transport it can also include new vehicles to provide missions addressing first responder services, emergency services, public services, and priority cargo delivery to increase quality of life and deliver societal benefits in a sustainable manner.

Delivery of the Digital European Sky by 2040 is ambitious and will require, from 2020 onwards, a new way of working, combined with changes to the regulatory framework, to further shorten innovation cycles and time to market. It is only by introducing these bold changes in a coordinated and timely manner that the aviation infrastructure will be able to transform itself to effectively and sustainably cope with the entry into service of new types of vehicles and increasing air traffic demand expected to shape fundamental changes to aviation.

2.2 Challenges throughout the Horizon Europe timeframe and up to 2040

The vision that is outlined in the previous section implies a significant transformation of the ATM system as we know it today. In addition to the current challenges of acquiring real buy-in from states and crucial staff, key challenges like environmental efficiency, scalability, resilience and interoperability must be addressed and solved in the next few years. Figure 6 presents the challenges of the SRIA that are covered in the sections below.

2.2.1 Supporting evolving demand for using the European sky

While in the coming years, air traffic demand may be significantly affected by the COVID-19 pandemic, it is anticipated that by 2050 air traffic will nevertheless consist of tens of millions of flights annually. As shown in Figure 7., the vast majority of this traffic will originate from new types of vehicles (e.g. drones) operating in airspace that is so far less used: VLL airspace (initially below 150 m or 500 ft.) away from aerodromes. The airspace at and above 500 ft., which includes both controlled and uncontrolled airspace will be profoundly different from today due to the increased density and diversity of air traffic. Also here, the interactions between the various types of traffic will not necessarily be driven solely by humans (e.g. single pilot operations (SPO), which come with an increased degree of airborne automation, unmanned cargo requiring

Figure 6 – THE FOUR TYPES OF CHALLENGES TO BE ADDRESSED

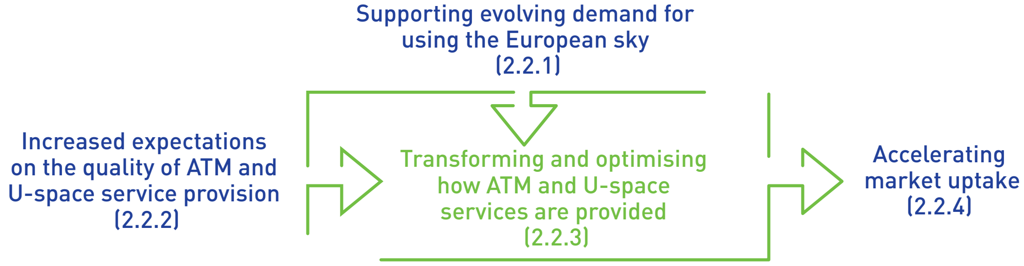
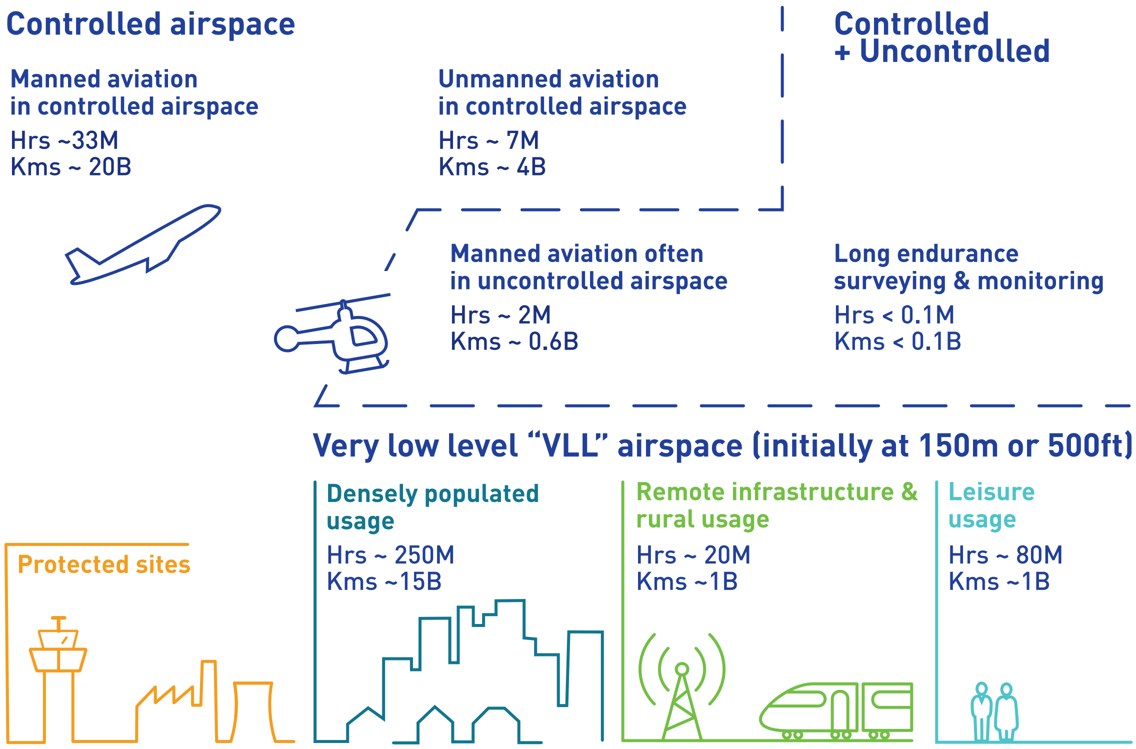


Figure 7 – 2050 OUTLOOK OF FUTURE INCREASED USE OF THE AIRSPACE BY MANNED AND UNMANNED OPERATIONS



Source: European drones outlook study, 2016

fully automated ATM interactions). The entry into service of the most significant of these new types of aircraft is expected to scale up gradually from 2030, which is when the supporting infrastructure needs to be ready to accommodate this new air traffic. Demand for access to lower-level airspace is already growing rapidly as more and more drones are taking to the sky every day, for leisure but also increasingly to deliver professional services (e.g. for inspections and data collection, and for public safety and security purposes, but soon also for parcel delivery and urban air mobility). In addition, by 2035, daily high-level operations (HLO) are expected and their transition from a segregated and/or non-segregated airspace have to be well established with appropriate regulations. Two key implications follow. First, managing this level of air traffic at current productivity levels will be unsustainable, given the cost implications and the limited gains in efficiency that can be achieved by further splitting of sectors (limited airspace elasticity). Second, increased traffic levels and new forms of traffic (including military traffic such as remotely-piloted aircraft systems and fifth generation fighter aircraft) with diverse communication technologies, flight and speed patterns, etc., will lead to unprecedented levels of heterogeneity and complexity in vehicles, requiring further automation, connectivity and interoperability. On both counts, the uncertainty of the timing and magnitude of the change requires the future ATM system to be fully scalable and performance-based to ensure a cost-efficient ATM system with safety at or above current levels.

2.2.2 Increased expectations on the quality of ATM and U-space service provision

While the benefits of continued growth in air traffic for EU citizens are clear in terms of mobility, connectivity and availability of new services (e.g. those enabled by drones), this growth represents a significant environmental challenge in the years to come. Concerns in this regard in Europe and worldwide are prompting the aviation industry to step up its efforts to address the environmental sustainability of air travel and reach the EU's carbon neutral goal by 2050. While the Clean Aviation partnership aims at reducing the actual emissions from aircraft, the Integrated ATM partnership will need to deliver quick results for the challenges already targeted by the SESAR programme so far, of optimising traffic management procedures such that they add minimal inefficiencies to the "perfect trajectory" and of delivering sufficient capacity, resilience and scalability in the system to allow such optimised procedures to be followed at all times.

There is growing pressure on the aviation sector to reduce its environmental footprint. Citizens in general and air passengers in particular increasingly expect eco-friendly, smart and personalised mobility options that allow them to travel seamlessly and efficiently and experience minimal noise discomfort from aviation. They want quick and reliable data to inform their travel choices, not only on schedules, prices and real-time punctuality, but increasingly also on environmental impacts. Coming out of the COVID-19 crisis, the ATM infrastructure has to be modernised at a rapid pace and operational efficiency, at airports and terminal areas, but also in en-route airspace, has to be increased rapidly to bring significant immediate environmental benefits by enabling all aircraft to optimise their environmental footprint from departure gate all the way to arrival gate.

While some immediate relief can be brought by existing best practices and better alignment of the airspace with traffic, significant R&I effort is still needed to develop traffic management capacity, enabling "perfect flights by design" (including for the next-generation aircraft, which will be cleaner and quieter) from an emissions perspective. This shall eliminate to the maximum extent possible the traffic management effects that would result in generating unnecessary emissions.

Historically, ATM-related accidents[1] have been only a very small portion (< 1%) of the total number of aviation accidents. With such a small room for further improvement, the main challenge in implementing the SRIA will be to ensure that system changes introduced by the new solutions do not degrade today's safety levels and where possible improve them, especially with the wider introduction of new vehicle types. The disruptive nature of some innovations may also require a redefinition of the safety management framework.

The resilience of the ATM system lies in its ability to adjust to expected and unexpected events (staffing problems, significant weather, system failures, cyberattacks, temporary surges in needed capacity) in order to sustain required operations and secure sufficient capacity, then return when the operational situation is again normal. Today, whenever there is a local disruption that temporarily reduces capacity below demand, there are generally three options:

- Flights are delayed until capacity becomes available.
- Flights are re-routed through airspace with spare capacity.
- Flights are cancelled.

The need for more resilient ATM operations will increase with higher traffic demand, placing pressure on the system to operate even closer to its capacity limits. Not only will more flights and more passengers be impacted if part of the system is forced to operate at reduced capacity, it will also take more time to recover to normal operations. This is where two of the previously listed flagship topics of the SRIA (Figure 2), namely *"capacity-on-demand and dynamic airspace" (see 3.3) and "virtualisation and cyber secure data sharing"* (see 3.5), need to be delivered. They aim to ensure the continuity of efficient air traffic service provision despite disruptions by enabling a temporary delegation of the provision of air traffic services to an alternate provider with spare capacity.

From a customer-centric perspective the resilience of the service is also closely related to the expectation of seamless connectivity between transport modalities. Airports and in-city vertiports for urban air mobility will thus need to become integrated, efficient and sustainable

1 Where at least one ATM event or item was judged to be DIRECTLY in the causal chain of events leading to the accident (Performance Review Report definition)

multimodal transport nodes that support connectivity across European society. The challenge set in Flightpath 2050 [4] of 90% of European travellers being able to complete their door-to-door journey within four hours remains applicable and underpins the need for a multimodal approach.

The urban air mobility providers and their customers as well as other new categories of airspace users, like very low level drone operators and medium to very high altitude long-endurance operators will bring a whole new set of expectations on the services provided by the aviation infrastructure. Many of them are planning to operate without a human pilot involved, posing new challenges for air traffic management personnel to interact with them and deliver their services. Nevertheless, these new airspace users expect to have access to the airspace where and when they plan to operate, they also expect the highest levels of safety and even lower charges for the services provided.

While sharing various quality of service expectations with civil users, military airspace users have further expectations due to their specific purpose. In particular the ability to improve the flexibility of military missions, and thereby their effectiveness, is an important expectation. Another challenge will be to satisfy the military need to have secure access to the increasing amount of aviation (and other) data that allows them to improve the maintenance of their recognised air picture (RAP) and to distinguish real security threats from false positives.

2.2.3 Transforming and optimising how ATM and U-space services are provided

Despite the successful deployment of technologies already developed under the SESAR project, Europe's ATM infrastructure remains largely fragmented and operates with a low level of automation support and data exchange intensity (the primary communication technology in ATM today is still analogue radio through which decisions are exchanged by voice between air traffic controllers and pilots). The SRIA aims to deliver innovations that are not "business as usual" or incremental but breakthrough solutions as the overall system is getting ever closer to its limits in terms of capacity and its ability to manage traffic safely and environmentally efficiently.

Increasing the performance of the ATM services is not an easy challenge. With a strong reliance on the cognitive skills of air traffic controllers, pilots and other operational staff, trying to increase the performance beyond the current limits while maintaining the expected level of safety requires a very careful matching between automation and human skills. Trajectory management systems will have to reach a very high level of sophistication and redundancy before they will be sufficiently trusted by ATCOs to give up their detailed awareness of the tactical separation situation. The increased complexity of handling a wider variety of vehicles with very diverse performance characteristics adds to this challenge, as does the amount of data that makes up the "digital twin" of each flight.

To achieve the very high levels of automation that are targeted, the best possible use of artificial intelligence (AI) will need to be developed. AI can identify patterns in complex real-world data that human and conventional computer-assisted analyses struggle to identify, can identify events and can provide support in decision-making, even optimisation. A myriad of ATM non-safety critical AI-based applications can already be developed today to improve all aviation/ATM areas. The SRIA is however focused on research and innovation actions for safety-critical applications, notably for systems that are aiming for high levels of automation. Indeed safety demonstration, explainability of AI, joint human system partnership and ethical aspects are challenges for which aviation/ATM must be ready to fast track appropriate and robust responses. Any developments on AI will need to be synchronised with the recently published EASA AI roadmap [17].

While the current European ATM system is a patchwork of bespoke systems and networks connected by a complex array of different interfaces, often utilising national and proprietary standards, it is clear that the target open architecture of the European ATM system, including for the provision of U-space services (see Figure 5.) will rely on increasingly interconnected systems that utilise modern technologies (including internet of things - IoT) and interoperability to deliver operational improvements through a shared view of all aeronautical information.

Two key challenges threaten these benefits:

- Increased interconnectivity and integration both in terms of interactions between actors (ANSPs, U-space service providers, airlines, airports, aircraft, drone operators) and CNS systems expand the attack surface and create new vulnerabilities, for example through third-party access to networks and systems.

- Interoperability implies an increased use of common components and/or standardised interfaces and service definitions, and a possible loss of diversity and robustness. This increases the likelihood of introducing common vulnerabilities into the systems and so needs greater attention and the involvement of expertise from other critical infrastructure sectors.

In particular, the principles of system-wide information management (SWIM) on which the service interfaces are built, presents opportunities to establish the necessary IT service management principles and cybersecurity architecture at an early stage of development, before the costs of retrofitting access control, intrusion detection and forensics become prohibitive.

For ATM and U-space services, a number of guiding principles will have to been defined for the organisational and technical measures that are needed to encourage cyber resilience. In general, cybersecurity practices in ATM will need to be adapted to comply with the relevant European regulatory framework, which is not always aviation specific: GDPR, NIS Directive, EC 373/2017. There is a need to define and agree acceptable means of compliance, guidance, manual, standard and training requirements. Though needed, the current State-based approach is neither sufficient, nor sustainable in a domain like aviation where by definition activities are international and with such a level of interoperable connections and interfaces. For example, it is essential to address the requirements for cross-border collaboration in the context of cybersecurity, as well as sharing of information about cyber threats and vulnerabilities.

This whole transformation challenge is further complicated by the effects of the COVID-19 crisis. During the initial years of implementing this SRIA many aviation stakeholders may be struggling to survive and will prioritise their efforts on containing investment and operating costs and on ensuring business recovery. Investing effort and budget in transformations that will not bring immediate benefits will be very challenging. Nevertheless, if these do not take place, there is a significant risk that when demand does recover, the ATM infrastructure operations will not be able to handle it with the expected quality of service.

2.2.4 Accelerating market uptake

Tackling the aforementioned challenges is not just a matter of technology alone; it also requires a rethink of how these developments are to be brought into operational use. Historically, changes in technology and operations in air traffic management take a long time from an initial idea to operational use. The safety critical nature and the need for global standards play an important part in that. They do not, however, fully explain why some solutions do not progress to implementation after the research is considered complete, or why there are gridlocks between complementary airborne and ground deployments. Recent European Court of Auditors reports ([23],[24]) found that the current policy, R&I and deployment initiatives have generated a change process, but that more efforts are needed in order to realise the full benefits of ATM modernisation: "*It is therefore necessary to accelerate and better focus efforts on transforming the European ATM system into a digital, scalable and resilient network, through an approach coordinated at EU level*"

Therefore, the cycle of change has to be made more efficient, thus shortened, identifying more quickly the most promising solutions and promoting early movers, inside and outside the partnership, through networks of digital labs and demonstrators close to operations.

The new ways of working would involve the following:

More agility: creating solutions through prototypes and demos developed in smaller teams with shorter time frames; developing solutions by addressing service-related challenges without prejudging upfront what the optimal technical solution is; creating digital innovation labs to fast-track R&I, perform quick prototyping, incubate new ideas, and validate early against operational scenarios exploiting real-world actor-induced uncertainty.

People: encouraging a shift away from a traditional product-centric strategy to one that focuses on the end user, stimulating entrepreneurship, recognising low risk areas of change, putting in place a more risk-taking culture and creating the buy-in from operational staff.

Focus: on disruptive innovations that can reduce innovation cycles from about 30 years to about 5-10 years. To achieve this, the development and deployment of the integration of drones into the airspace, and in particular the development and implementation of U-space services, may be used as a 'laboratory' that can support faster life cycles in the manned aviation environment; in addition, 'sandboxing' between organisations may allow faster times to market.

Standards & certification: To keep pace with technological advances, the demonstrator network will closely involve the relevant authorities and bodies to finalise the development of the next generation standards that are responsive to policy needs, agile, open and joined up.

Better regulations: that will support innovation — through market take-up, incentives for early movers and focus on delivery of services — with an emphasis on what services should be provided and how, rather than on what technologies should be implemented. This innovative approach would allow better connections and synchronisation between ground-based developments and the airborne industry. A coordinated approach between Member States and European-wide rulemaking will be essential.

These new ways of working will need to be connected to industrialisation that needs to be efficient, short and closely linked to operations to enable quick deployment as full benefit is generally only achieved by deployment across the industry.

2.3 Instruments for accelerating innovation

The implementation of this SRIA requires the delivery of a wide range of technological and operational solutions that are currently at various maturity levels. Three instruments that are described in more detail in the Integrated ATM partnership proposal are foreseen as principal means to deliver the necessary R&I in an accelerated way.

Exploratory Research drives the development and evaluation of innovative or unconventional ideas, concepts, methods and technologies that can define and deliver the performance required for the next generation of European ATM system. Activities cover low technology readiness level (TRL) research, but by using e.g. digital lab incubators, they may more quickly evolve to higher levels of maturity.

Industrial Research & Validation develops, assesses and validates technical and operational concepts in simulated and real operational environments according to a set of key performance areas. In order to achieve faster innovation cycles, SRIA implementation will need a more agile management approach, shifting the focus to the next generation of enabling platforms and their end-user ecosystems. It is also crucial to confront and challenge concepts and solutions as from this stage with the behaviour of ATM actors as observed in recordings of real ATM operations. This will stimulate rapid decision and learning cycles, a risk-taking culture and will create buy-in from operational staff.

The **Digital Sky Demonstrator** instrument will be closely connected to the standardisation and regulatory framework, and will provide a platform for a critical mass of "early movers" representing at least 20% of the targeted operating environment to accelerate market uptake.

The innovation pipeline makes it possible to transition more rapidly from exploration (low TRL) to demonstration (high TRL) and to the market. Demonstrators will take place in live operational environments and put to the test the concepts, services and technologies necessary

Instrument	Maturity levels	Effort share
Exploratory research	Pre-TRL1 Scientific Research TRL 1 Basic principles observed and reported TRL 2 Technology concept and/or application formulated	3.5%
Industrial research	TRL 3 Analytical and experimental critical function and/or characteristic proof-of concept TRL 4 Component/subsystem validation in laboratory environment TRL 5 System/subsystem/component validation in relevant environment TRL 6 System/subsystem model or prototyping demonstration in a relevant end-to end environment (ground or space)	44.75%
Digital Sky demonstrator	TRL 7 System demonstration in an operational environment TRL 8 Actual system completed and "mission qualified" through test and demonstration in an operational environment	51.75%

Source: SESAR Joint Undertaking

to deliver the Digital European Sky. This will help ensure buy-in from the supervisory authorities and operational staff, providing tangible evidence of the performance benefits in terms of environment, capacity, safety, security and affordability. Typically, these activities address up to TRL8.

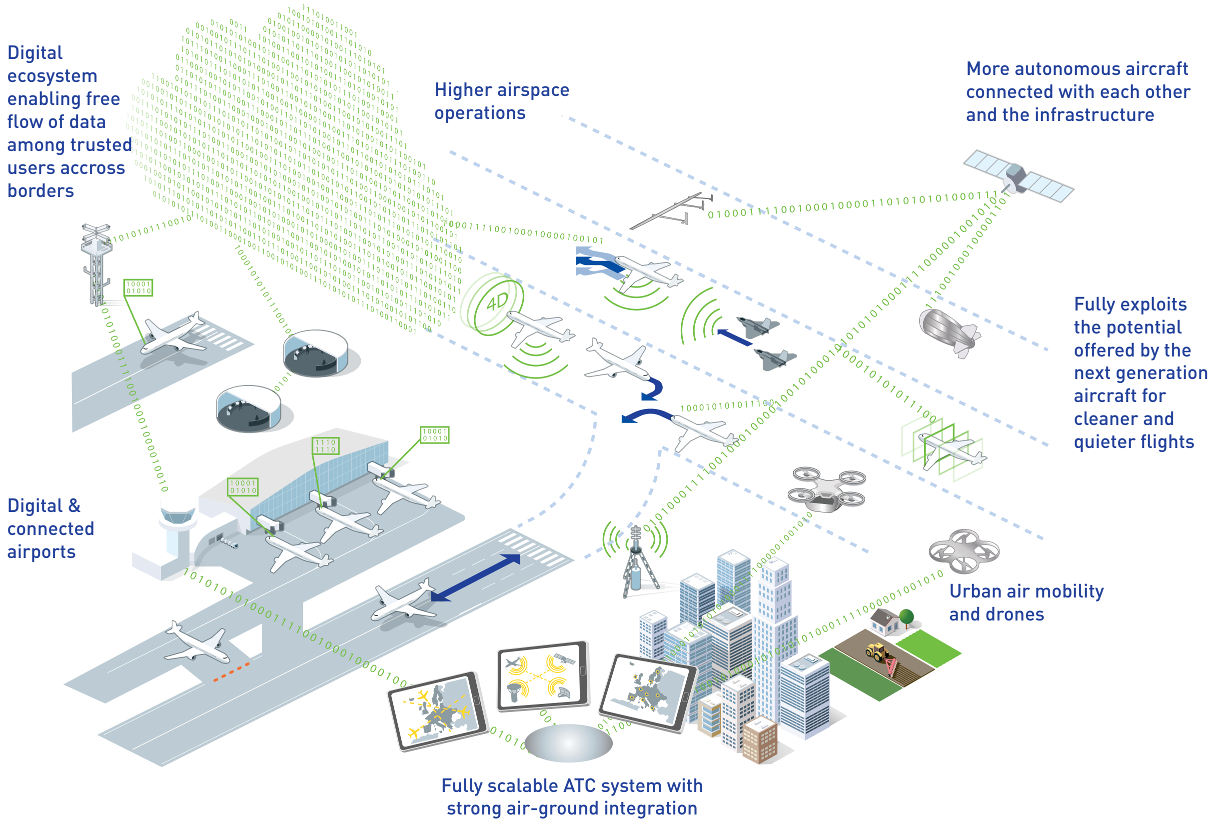
In the roadmaps in Chapter 3 the various actions each correlate with one of these instruments. Furthermore they provide complementary information on foreseen deployment actions that would follow on from previous research and from the proposed research and innovation in this SRIA.

2.4 Impact and stakeholder contributions

The vision, objective and expected impact of the SRIA can only be achieved by coordination with all stakeholders that develop, supply, operate, use and regulate the Integrated ATM services and infrastructure supporting aviation in Europe, covering all technology readiness levels (TRL).

The implementation of this SRIA will thus require the establishment of a strong implementing body for R&I that closely cooperates with industrial, operational, staff representation, institutional, national, standardisation and certification actors active in different phases of the SESAR innovation cycle including the SESAR

Figure 8 – IMPACT TO BE ACHIEVED BY THIS SRIA



Source: SESAR Joint Undertaking

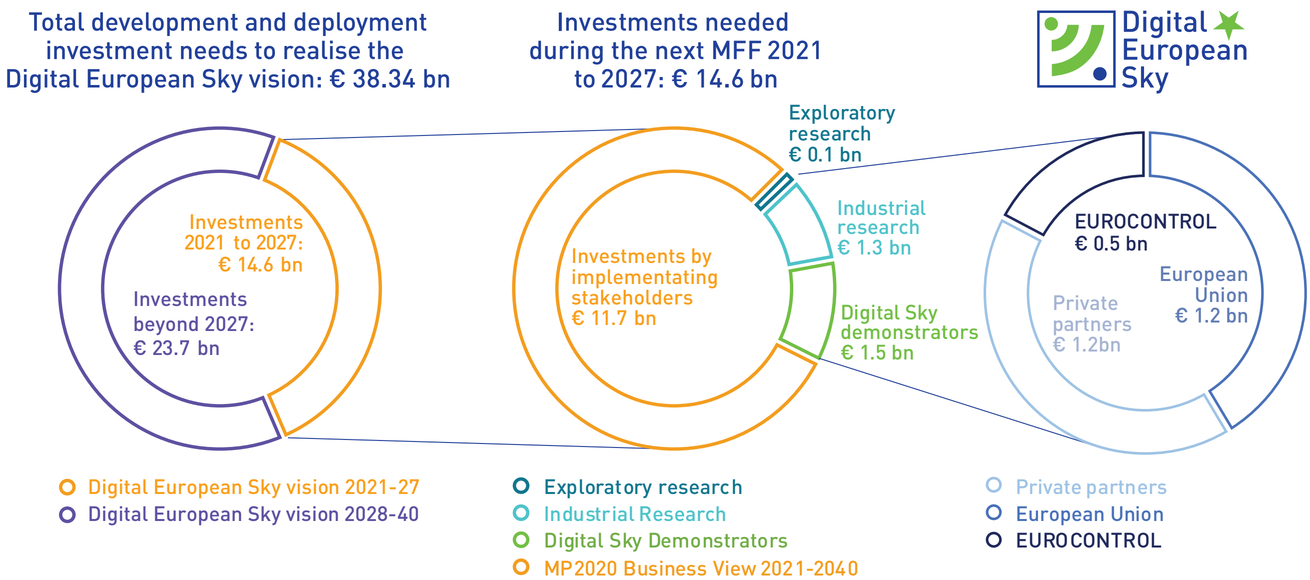
deployment phase, mandated by Commission Regulation and supported financially by the Connecting Europe Facility Programme. To that end, Member States will be closely associated to discuss priorities and synergies, which is critical to the success of the initiative.

We estimate that it will take a total investment of EUR 38.3 billion to complete the deployment of the Digital European Sky between 2021 and 2040, EUR 14.6 billion of which will need to be spent during the Horizon Europe multiannual financial framework (MFF). Of these investments needed during the MFF, EUR 2.9 billion will be needed to execute the flagship activities defined in this SRIA. Approximately half of this investment will be dedicated to accelerating the deployment of SESAR 2020 solutions, mainly through the creation of a Digital European Sky demonstrator network. The rest will be dedicated to research and innovation on further solutions needed for phase D of the European ATM Master Plan. Within the EUR 2.9 billion effort to support this SRIA, EUR 0.5 billion of effort will come from EUROCONTROL, while the remaining is foreseen to be evenly split between EUR 1.2 billion from the European Union and EUR 1.2 billion from public and private partners, thus establishing an appropriate risk sharing partnership.

2.5 Maximising impact by developing effective synergies

The SRIA aims to contribute to Pillar II of Horizon Europe, where it fits in the Climate, Energy and Mobility cluster. The SRIA implementation will be coordinated with other mobility solutions with the aim to build consolidated roadmaps and action plans for climate-neutral mobility solutions. This will also address common sectorial issues such as transport multimodality,

Figure 9 – SHARE OF PRIVATE AND PUBLIC CONTRIBUTIONS TO EXECUTE SRIA UP TO ITS FULL DEPLOYMENT BY 2040



Source: SESAR 2020 PJ.20 (W2) project partners

automated vehicles and the decarbonisation of the sector. In particular, a specific and close coordination between the European partnerships for Integrated ATM and Clean Aviation is believed to be essential for the aviation sector.

Both aviation-related partnerships proposed under the Horizon Europe programme will play an essential role in making the aviation sector successful in achieving the environmental and mobility goals set out by their common vision for Europe's aviation, while contributing to the objectives of the European Commission, in particular to the Green Deal. These goals will be attained through the research and development of key innovative technologies for the decarbonisation, energy transition and digital transformation of the aviation area.

Opportunities will be actively sought for running joint demonstration activities. This would enable the two programmes to show in practice that the anticipated changing performance characteristics of new aircraft configurations with more sustainable propulsion systems can be accommodated in the best possible way by the changes in ATM operations. It could in particular allow the programmes to evaluate the combined benefits and impact of particular solutions, for example, in the measurement of the aggregated effect of green operations and green aircraft on the achievement of the overall decarbonisation goal.

A first set of potential areas to demonstrate the synergy effects has been identified (this list is not exhaustive):

- Combined simulations
- Joint performance and impact assessments
- Autonomous airborne operations
- Airport turn around processes for new vehicles
- Sharing of performance profiles of new Clean Aviation aircraft configurations for use in fast-time ATM simulations

The implementation of these joint demonstration activities should be further elaborated once the two programmes are up and running under Horizon Europe.

Considering that the digital transformation of aviation is at the core of the SRIA goals, it strongly echoes the ambition of the Digital, Industry and Space cluster. It is in many ways complementing this cluster by addressing aviation-critical applications. Therefore, it is essential to put in place synergies with all relevant digital initiatives outside the Climate, Energy and Mobility cluster. For example, artificial intelligence, cybersecurity and high performance computing are cross-sectorial issues that require deep coordination, especially for the development of use cases and the application of European standards. In addition, a connection will need to be made to the achievements of the European space policy and its associated research agenda [7]. With satellite communication, navigation and surveillance services considered as essential enablers to the Digital European Sky, the SRIA execution will also need to connect closely to GALILEO, IRIS and other European space developments, and to build on the achievement of SESAR 2020 in the space domain to engage further with the space actors in the innovation ecosystem.

Finally, subject to the progress made in developing hydrogen applications for aviation propulsion, synergies may need to be sought with the proposed European Partnership for Clean Hydrogen to optimise the connection between the processes for hydrogen storage, transport and fuelling with the turn-around processes of airborne vehicles (manned and unmanned).

3 Digital European Sky portfolio

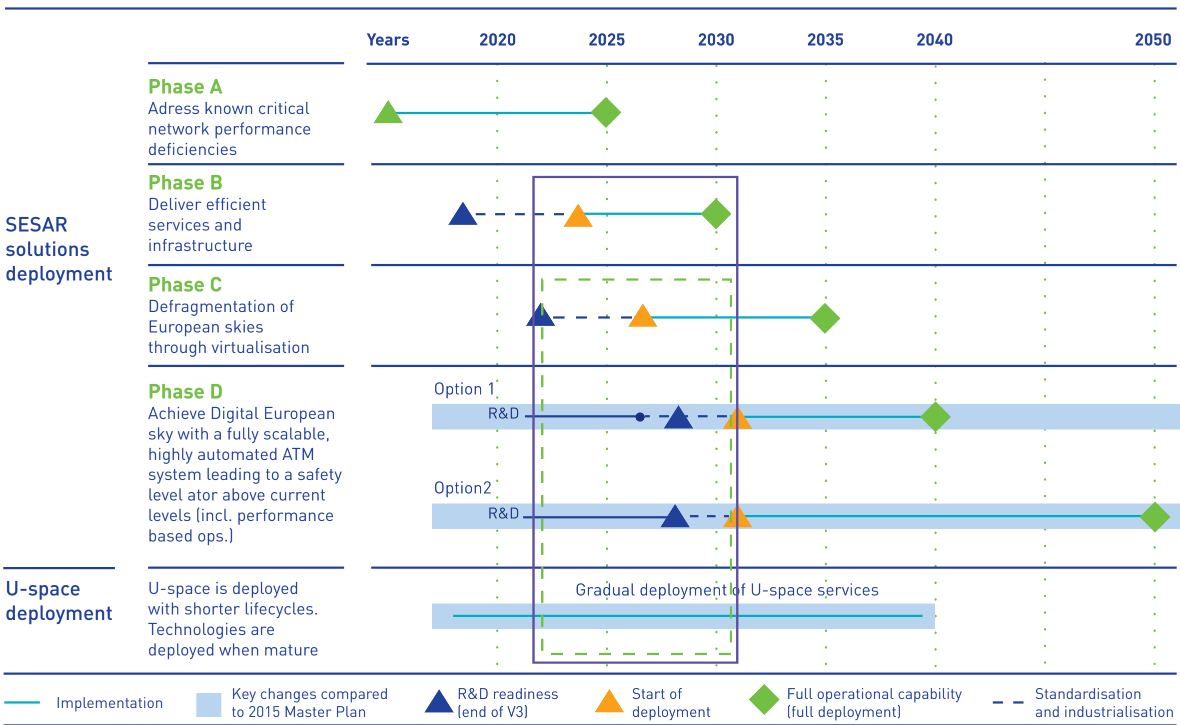
The portfolio of the Digital European Sky SRIA is presented in this document through its flagship activities.

As can be seen in Figure 10. the activities taking place during the Horizon Europe MFF timeframe cover more than research and innovation (R&I) alone. Solutions previously developed by SESAR and other programmes will be implemented, which are, for example, covered in the operational excellence programme executed by the Network Manager.

For the sake of completeness, the different roadmaps in the following sections cover the actions within the blue frame in Figure 10., while the actual R&I actions in this SRIA match with the green frame and thus with phases C and D of the European ATM Master Plan (see Figure 3.).

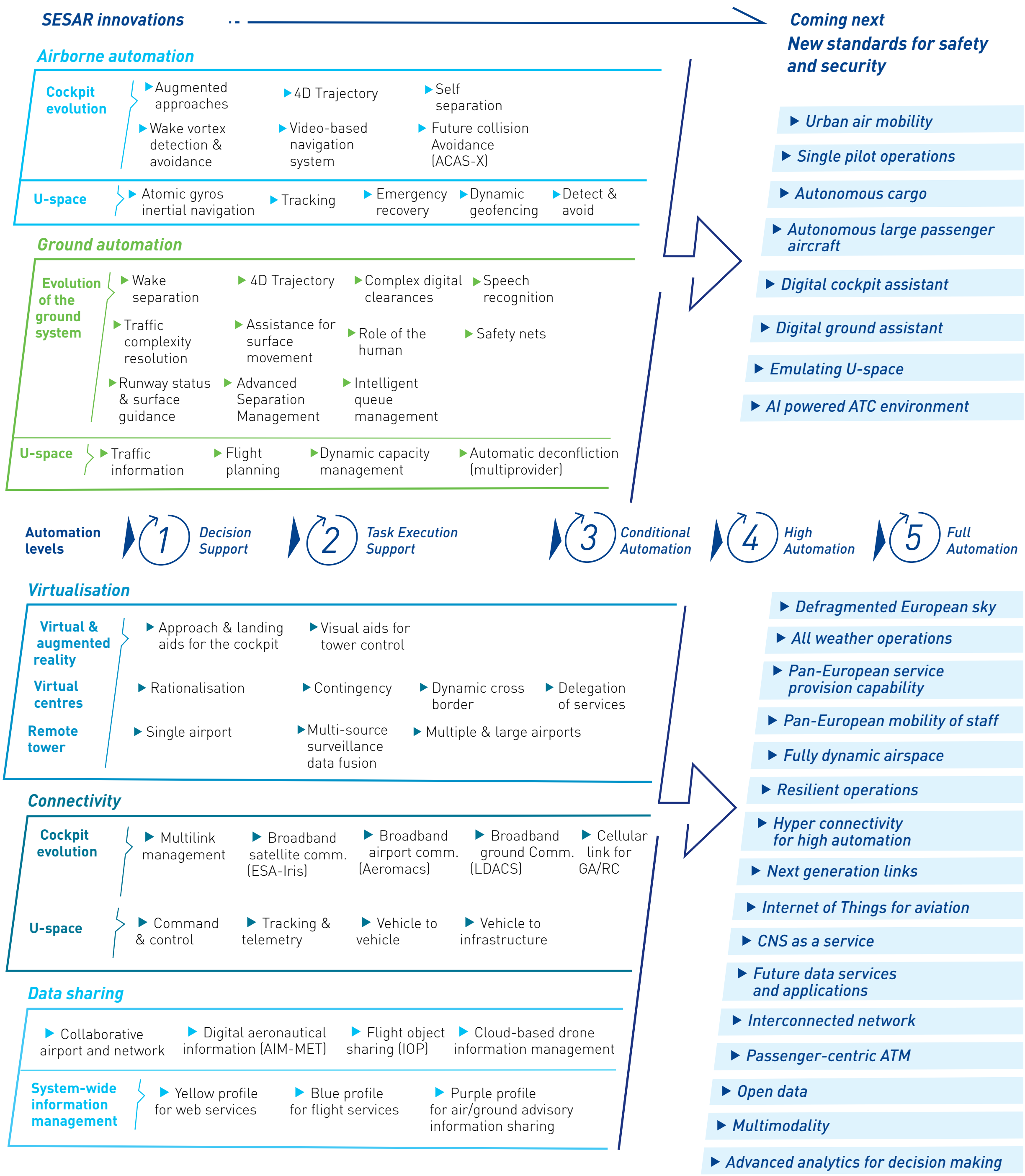
The implementation of phase D of the European ATM Master Plan aims to prepare the Digital European Sky. In the ATM Master Plan we find Figure 11., which provides an insight into the disruptive automation to be addressed in this phase.

Figure 10 – TARGET ROLLOUT OF SESAR



Source: Based on ATM Master Plan 2020 edition

Figure 11 – DISRUPTIVE AUTOMATION FOR THE DIGITAL EUROPEAN SKY



Source: ATM Master Plan 2020 edition

3.1 CONNECTED AND AUTOMATED ATM

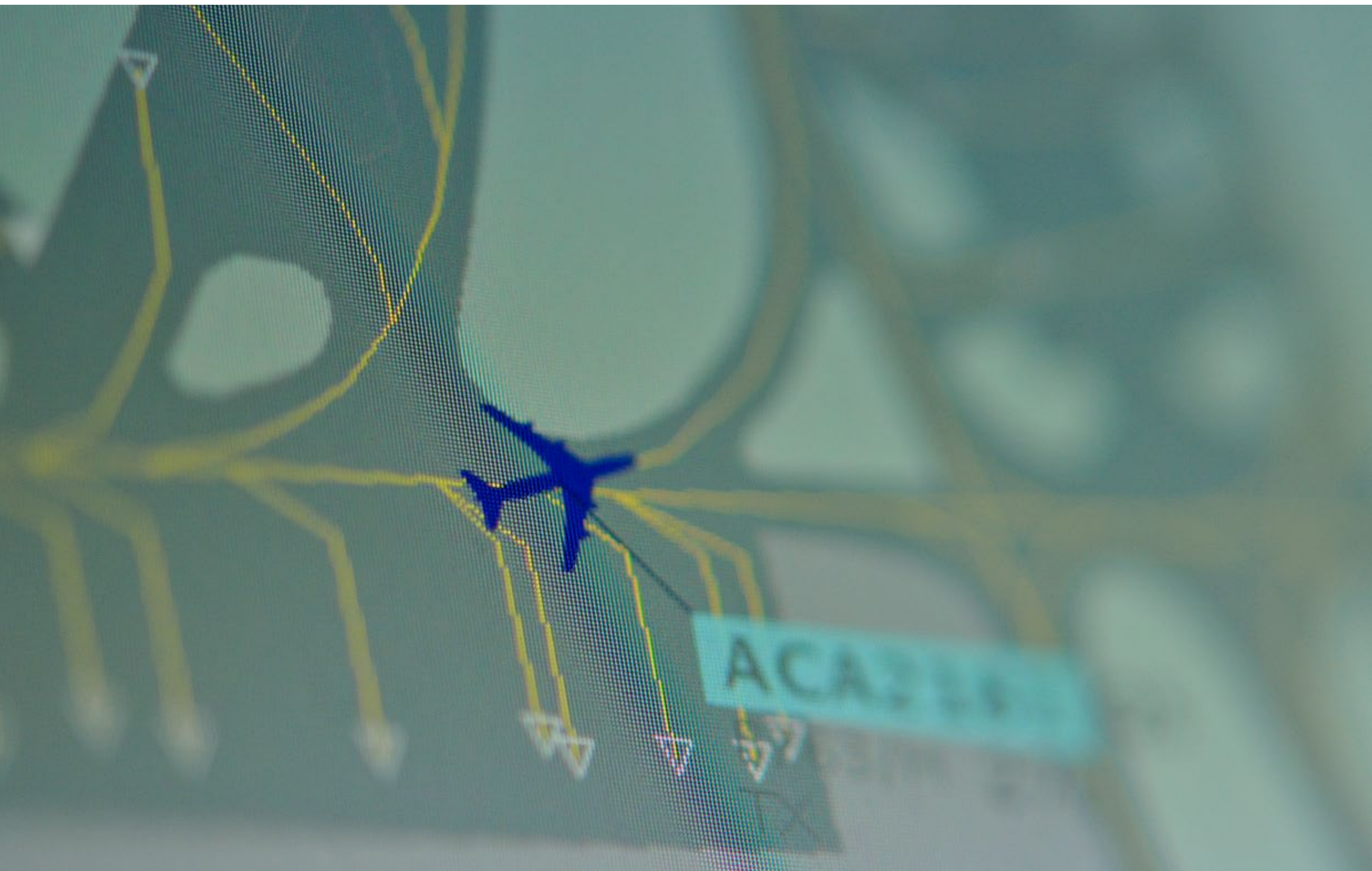
PROBLEM STATEMENT

Europe's ATM infrastructure operates with low levels of automation support and data exchange, leading to rigidity, lack of scalability and resilience, and an inability to exploit emerging digital technologies, including in support of new airspace users. The future architecture of the European sky requires increased automation in air traffic control and an infrastructure commensurate with the performance required by each airspace user type and environment, including those in the transition areas between Europe and neighbouring ICAO regions which may have specific regulations and challenges.

DESCRIPTION OF HIGH-LEVEL R&I NEEDS/ CHALLENGES

The Digital European Sky vision recognises that the future ATM environment will be increasingly complex, with new airspace vehicles flying at different speeds and altitudes compared to conventional aircraft. Moreover, there will be increasing pressure to reduce the costs of the ATM infrastructure while improving performance.

Secure data-sharing between all the components of the ATM infrastructure and the relevant non ATM stakeholders is a key part of the Digital European Sky, together with automation using the shared data to improve ATM performance. This section identifies the specific research needed to realise the automation and connectivity vision of the European ATM Master Plan for the future ATM ground system.



Enabling the deployment of a performance-based communications, navigation and surveillance (CNS) service offer

Industrial research and demonstration of an integrated performance-based CNS service offer will be required building on the industrial research on selected technologies (e.g. SATCOM, AeroMACS, LDACS, etc.) carried out in SESAR 2020. This unified framework, made up of a backbone infrastructure, supported by a backup minimum operational network, will maximise cross-domain opportunities and synergies and will support various airspace concepts. The development of non-safety-of-life ATM applications using commercially available services (e.g. 5G, open SATCOM) will be required in order to contribute to a hyper-connected ATM system.

Advanced separation management (U-space integration and new separation modes)

Research is required to understand how different modes of separation provision enable inter-operable ATM and U-space services to co-exist, considering the diversity of aircraft performance characteristics and detect-and-avoid capabilities. For separation provided by air navigation service providers (ANSPs), full sharing of all relevant information between all actors, and fully harmonised trajectory prediction capabilities will allow advanced separation support to be provided to controllers in terms of resolution advisories for human or automatic implementation. Research that will consider predictive modelling and machine learning will contribute to develop advanced modes of separation (e.g. dynamic separation) benefiting from automation and improved connectivity. Formation flying, self-separation between drones themselves or with manned aviation (stay well clear) and pair-wise separation are some of the areas of research to be considered in order to adapt to the diversity of traffic in all phases of flight and in all classes of airspace.

Intelligent queue management

Research into additional extended arrival management (AMAN) capabilities is required so that current procedures, focused on transferring predicted arrival holding times from the terminal manoeuvring area (TMA) to the upstream airspace to reduce holding, can evolve towards individual target times for each aircraft. This can be achieved through arrival metering points that take into account the cross impact of multiple arrival sequences sharing the same airspace (overall network impacts) and ensure optimum use of performance-based navigation arrival routes, enabling aircraft to fly continuous descent approaches from en-route through the TMA. This area, including relaying of instructions from air traffic control (ATC) to pilots, is a promising one for higher levels of automation as it can be carried out under ATC supervision without impacting separation and sector team management. The efficient strategy and resolution of simultaneous constraints (brokerage function) related to multiple extended AMAN advisories also requires further research. Furthermore, research should consider how larger unmanned aircraft, such as cargo drones, could fit into airport arrival queues, and whether arrival management automation could be extended to possible queues of air taxis approaching a congested air taxi hub. Research into departure queue management automation will also contribute to improvements in uninterrupted aircraft climb profiles from airport to free route airspace. As with arrivals, departure queue management automation is dependent on the exchange of highly accurate trajectory information between all actors (i.e. airport, ANSP, aircraft operator); such techniques are likely to also apply to drones, air taxis and larger unmanned aircraft.

Runway use optimisation through integrated use of arrival and departure time-based separation (TBS) tools

The most modern time-based separation tools are already good examples of the value of automation in ATM. Research is required to further improve the whole runway usage process, combining arrival and departure capabilities. Data-sharing between airport collaborative decision-making parties, arrival and departure managers and time-based separation tools will allow the dynamic optimisation of the runway(s) based on prevailing operational needs. Such solutions will, for example, choose the most appropriate departing aircraft to make use of an arrival gap, sharing data with the airport systems to ensure the departing aircraft is loaded and taxies to be in the right place at the right time.

Airport automation including runway and surface movement assistance for more predictable ground operations

Airport ATC will also benefit from further automation support to manage increasing complexity. Further research is required into the automation of stand planning, taxi routing and ground de-confliction, and runway use optimisation, based upon improved and increasingly accurate data-sharing between applications. A holistic view, beyond the integration of airport operations plan (AOP) and network operations plan (NOP), integrating different technologies and data sources combined with artificial intelligence/machine learning will bring improvements to ground operations and enable more collaborative decision-making between stakeholders, thus improving predictability and the network performance as a whole.

Integration of safety nets (ground and airborne) with the separation management function

The separation assurance of the future aviation ecosystem will require close conformance monitoring of the negotiated and authorised flight trajectories throughout the execution phase, to be coupled with the advanced defences provided by independent ground-based and airborne safety nets. The use of those trajectories in the progressively more automated detection, classification, resolution and monitoring of conflicting profiles in the planning and tactical phases of ATM will minimise the opportunity for separation to be eroded. However, consideration as to the level of independence of the safety nets from the other aspects of control will be critical as the levels of autonomy of those other systems increase.

Role of the human

The goal of automation is not to replace the human but to optimise the overall performance of the socio-technical ATM system and maximise human performance[2]. This will require the development of the role of the human in parallel with ATM concepts and technological developments. New tools are needed to support continuous, system-wide monitoring of all critical processing, including during degraded modes of operation or, for example, cyberattacks. New tools must also enable humans to make effective decisions, including where collaborative, co-adaptive and joint intelligence modes of decision-making are used. A move from executive control to supervisory control will require a thorough understanding of the implications for the humans and their interaction with the systems. The human-to-technology balance is likely to vary between domains, where some problems might be solved by automation with little human intervention, while other areas might require a human, monitored by an automated safety capability to solve the problem. Research will need to address all the roles, responsibilities and tasks of the different actors (airborne and ground, ATM and U-space, operating and technical), training needs and change management for the evolving roles as per the recommendations provided by the Expert Group on the Human Dimension of the Single European Sky [29].

Speech recognition for increased safety and reduced workload

Voice communications between air traffic controllers (ATCOs) and pilots are still not digitalised and are therefore not readily accessible for machine analysis other than through analogue voice recording analyses. While data communication or text-based transmission of data between ATCOs and pilots is envisioned to supplement radio communications in future operating environments, this capability is unlikely to replace radio communications completely in the near term. Therefore, research and development of a data-driven (machine learning oriented), reliable, error-resilient, affordable and adaptable solution to transcribe automatically the voice commands issued by air traffic controllers and its read-back confirmation provided by pilots is of high importance. The digitisation of controller and pilot voice utterances can be used for a wide variety of safety and performance-related benefits, such as pilot read-back error detection, pre-populating electronic flight strips and other tools using automatic speech recognition, estimating controller workload using digitised voice recordings, or anticipating ATCO actions and behaviour. This will greatly improve safety and reduce controller and pilot workload. Other potential uses of speech recognition could include the adaptation of ATM systems. Further pilot-centric applications are also identified in section 3.2.

Network-wide synchronisation of trajectory information

Providing trajectory advice (including uncertainty considerations and improved weather forecasts) to ATCOs for human confirmation or automatic implementation is essential for the realisation of the vision. While optimising cost and minimising environmental impact, this trajectory advice will not only assure separation but also address all other operational constraints, considering ad-hoc downstream and pilot requests or non-conformance, continuous descent and arrival management demands, downstream airspace availability and workload, AO business needs and equity, the evolution of certainty over the prediction horizon, ATCO preferences and ensuring workflow integration and redundancy and safe degradation.

2 See also [1] European ATM Master Plan, Edition 2020, Chapter 4.5

An implementation-ready maturity gate is foreseen for 2023 to verify whether full deployment of the currently researched interoperability solution is realistic in the Horizon Europe timeframe. Integration of this solution, if mature enough, in the Digital Sky demonstrator network will make it possible to accelerate its deployment. Alternatively, R&I activities could be required to find alternative solutions to support the pressing need for synchronised trajectory information in the network. The applicability of the current solution, or of any alternative, with the foreseen introduction of ATM data service providers (ADSP) will also need to be investigated to ensure a service-based and cost-efficient way forward. Additional research is needed concerning the network-centric flight data exchanges to ensure the Network synchronisation of trajectory data and provision of required flight data by different stakeholders during the flight planning and execution phases.

System-wide information management (SWIM)

SWIM implementation will be a key enabler in the achievement of global interoperability for data-sharing and leveraging hyper-connectivity in conjunction with the future communications infrastructure (FCI). Implementation activities will focus on completing the development, standardisation and implementation of the various SWIM profiles, in addition to a constant monitoring of stakeholder needs to ensure the appropriate definition of new SWIM services to further speed up their deployment based on clear use-cases in line with the ADSP requirements. Additionally, future seamless integration of ATM and U-space domains via SWIM (e.g. through the yellow profile) requires R&I actions in support of the provision of different services like registration and identification, dynamic airspace information and geo-fencing, flight planning and surveillance data.

DEPENDENCIES WITH OTHER INITIATIVES IF REQUIRED

Implementation of the Pilot Common Project (and CP1)[25] for queue management, flexible use of airspace and free route, initial SWIM and trajectory sharing will form the basis for more complex tools and increased automation, as described in this section.

Connected and automated ATM R&I initiatives will build on mature solutions described in the European ATM Master Plan as part of the airport and TMA performance and trajectory-based operations essential operational changes (EOCs). The U-space initial services will build on the foundation services defined as part of the U-space services EOC.

EXPECTED HIGH-LEVEL OUTCOMES AND PERFORMANCE OBJECTIVES

These activities will boost the level of automation that can be achieved for the relevant areas (see Figure 4). This will contribute to achieving the European ATM Master Plan vision to reach at least Level 2 (task execution support) for all ATC tasks and up to Level 4 (high automation) for some of the tasks. The impact for U-space services will be even higher, where the aspiration is between Level 4 and Level 5 (full automation) for all the relevant tasks. Higher levels of automation are considered an essential enabler for increasing the performance of the socio-technical ATM system.

An affordable and service-oriented way of sharing trajectories across ATM actors will be available, enabling the capacity, cost efficiency, operational efficiency and environmental performance ambitions of the European ATM Master Plan for controlled airspace and airports. Unmanned traffic will have been integrated with manned traffic where required and will utilise additional airspace resources where available in an efficient and safe manner.

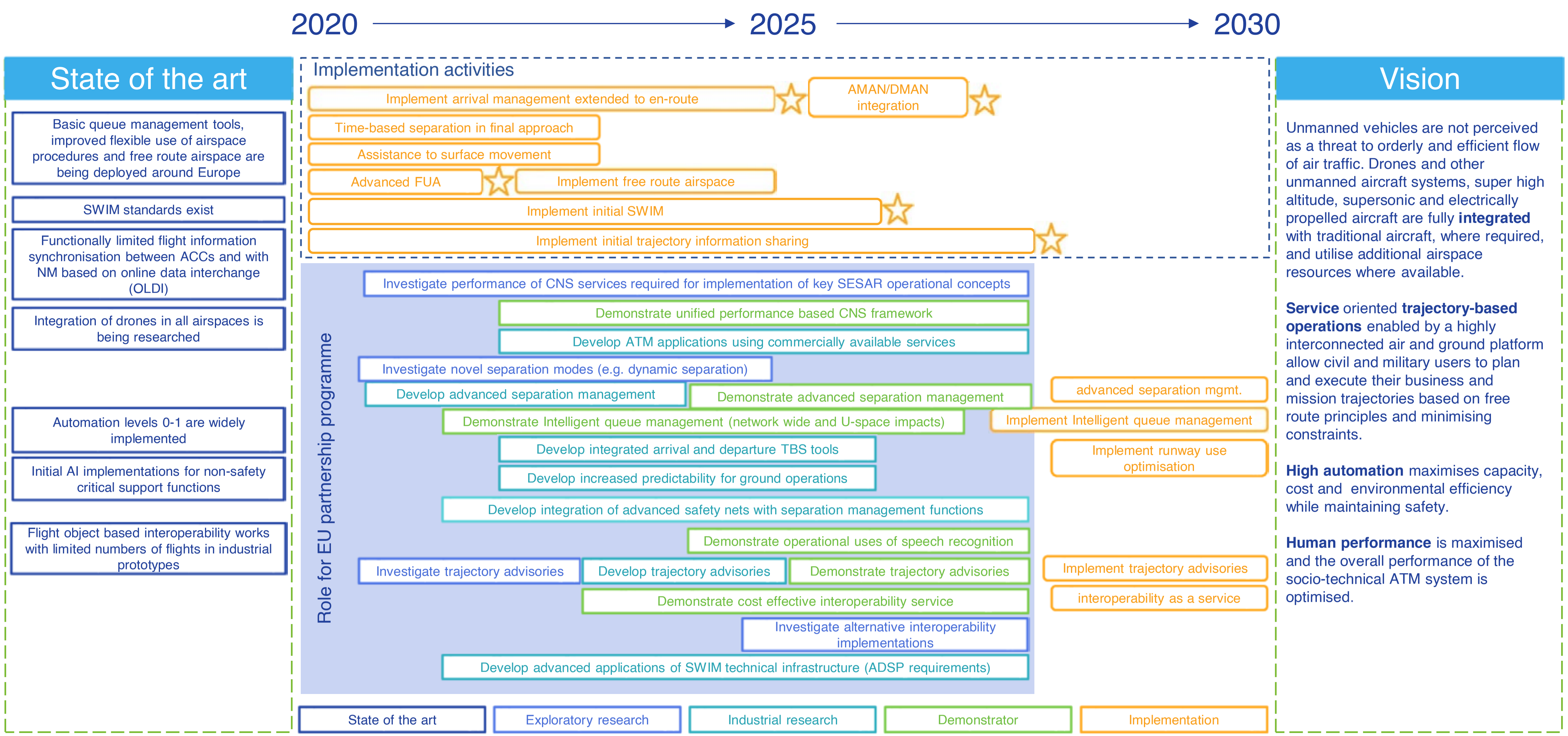
The future ATM system will deliver hyper connectivity between all stakeholders (vehicle-to-vehicle, vehicle-to-infrastructure) via high bandwidth, low-latency ground-based and satellite networks. Highly automated systems with numerous actors will interact with each other seamlessly, with fewer errors making the system scalable and even safer than today.

The following European ATM Master Plan Key performance areas are relevant to the Connected and automated ATM agenda where the following qualitative impacts will be enabled:

EXPECTED HIGH-LEVEL OUTCOMES AND PERFORMANCE OBJECTIVES (CONT'D)

Environment (+)	In addition to the environmental benefits of the operational efficiency improvements, intelligent queue management will enable more continuous descent and climb profiles.
Capacity (+)	The safe use of less restrictive separation modes, combined with increased level of automation support to ATC, will optimise the use of the airspace. Improvements in ground operations predictability and integration of advanced tools for arrival and departure will help to optimise runway use. Better connectivity between stakeholders, the use of shared 4D trajectories, interoperability and higher predictability brought about by increased automation will increase capacity.
Cost efficiency (+)	Increasing automation requires a significant investment before it can be used operationally, which could outweigh the capacity increases that can be achieved. It is expected that automation, when adopted consistently, will contribute to operational harmonisation and eventually to cost efficiency. A service-based approach and a well-defined required service level (e.g. for CNS services) will also help to achieve cost efficiencies.
Operational efficiency (+)	Shared 4D trajectories and interoperability will increase predictability, enabling the preferred trajectories to be flown with fewer tactical interventions.
Safety (+)	The performance of the system (human and automation) in an environment with increased automation includes safety, which will be maintained if not improved. The automation of some procedures shall ultimately lead to improved safety and fewer errors, which tend to be human-triggered. Additionally, the increase in data sharing will also foster the early detection of potential safety issues and their mitigation.
Security (-)	The increased connectivity between stakeholders could have a negative impact on the security of the system. This will be compensated for by research initiatives included in other sections of this SRIA.

ROADMAP 1 – CONNECTED AND AUTOMATED ATM



Source: SESAR 2020 PJ.20 (W2) project partners

3.2 AIR-GROUND INTEGRATION AND AUTONOMY

PROBLEM STATEMENT

Current ATM systems and technologies are not designed to allow the accommodation or full integration of an increasing number of new forms of mobility and air vehicles which have a high degree of autonomy and use digital means of communication and navigation. The future ATM needs to evolve, exploiting existing technologies as much as possible, and developing new ones in order to increase global ATM performance in terms of capacity, operational efficiency and accommodation of new and/or more autonomous air vehicles, i.e. supporting the evolving demand in terms of diversity, complexity from very low-level airspace to high level operations.

This progressive move towards autonomous flying, enabled by self-piloting technologies, requires closer integration and advanced means of communication between vehicle and infrastructure capabilities so that the infrastructure can act as a digital twin of the aircraft. Ultimately, manned and unmanned aerial vehicles should operate in a seamless and safe environment using common infrastructure and services supporting a common concept of trajectory-based operations.

Future operations should therefore rely on direct interactions between air and ground automation, with the human role focused on strategic decision-making while monitoring automation.

DESCRIPTION OF HIGH-LEVEL R&I NEEDS/ CHALLENGES

Enabling greater ground and airborne integration and wider performance

Greater air-ground integration will require solid, safe and secure means of communication and networking to transform, in a stepped approach, the current way to communicate.

From gate to gate, air to ground automation (A/G) will ensure the use of automatic selection of the link and frequency for communications by the pilot and ATC. This will support single-pilot and cross-border operations.

Air to air communication (A/A) will enable new operations (formation flights, etc.) and will support advanced separation management and safety nets in the context of the safe cohabitation of different types of air vehicles (High altitude, drones, airplanes, helicopters, etc.).

Satellite-based technologies can speed-up global deployment for other technologies through virtualisation of infrastructures and synchronised deployments for all stakeholders. Research is required to integrate these technologies into a multilink environment that supports the interoperability and hyper-connectivity of air-ground communication as well as the transition to IP-based communications.

By 2030, full IP-based A/G and A/A communications and the use of higher bandwidth mobile networks, including satellite-based solutions, are introduced and adopted, resulting in hyper-connectivity and rationalisation at network level, while A/G VHF voice and data are phased down with legacy fleet.

By 2035/2040, advanced and flexible means of communication are available:

- Seamless air-ground communication in support of human-to-human and/or machine-to-machine communications.
- Air-air communication in the context of ATM/U-space, in particular for the safe cohabitation of these diverse aerial vehicles.
- Ground to ground (G/G) communication enhanced via SWIM services among all stakeholders, i.e. Uspace, flight operations centre/wing operations centre (FOC/WOC) and ATM, in a safe, secure and resilient environment.
- By 2040, this will contribute to the development of a system of systems, possibly with elements based on artificial intelligence, with appropriate end-to-end safety assurance compliant with certification standards.

Integrated 4D trajectory automation in support of trajectory-based operations (TBO)

A common 4D trajectory, shared between every application that needs to process each flight, and updated by every application acting upon that flight, underpins ground-provided ATM. The accuracy of the trajectory is likely to improve at every stage of flight planning and execution. This requires earlier access to/sharing of detailed flight planning information, and all subsequent updates, publication of planning adjustments to the trajectory, and subsequently ATM trajectory adjustments, correlated with the aircraft's actual trajectory. These principles also apply to new airspace users, including drones, air taxis and high-altitude vehicles.

The integration/revisions of 4D trajectories will be based on the extended flight plan (eFPL) exchanges and require different flight and flow – information for a collaborative environment (FF-ICE) services in pre-departure and post-departure phase of flight, including the exchanges of planned 4D trajectory. The eFPL revisions during the planning and execution phase requires further research.

Implementation of the TBO concept and FF-ICE needs to consider all the different parts that in a synchronised way have to be developed and, as soon as integrated, can offer the relevant services to the airspace users.

Besides controller-pilot datalink communications (CPDLC) and human-to-human communication, datalink will also support machine-to-machine communication enabling the integration of extended projected profile (EPP) within the Network Manager system and further steps in 4D trajectory operations on the path towards ATM/U-space convergence.

Complex digital clearances

Industrial research activities will finalise the development of ground systems to enable complex digital clearances, taking into account traffic synchronisation, demand and capacity balancing and conflict management. In particular, after having implemented the initial concept of 4D trajectories via the sharing of trajectory (air to ground), there will be a need to go a step further on a larger scale thanks to CPDLC exchanges (ATN Baseline 2 improved clearances and instructions).

ATM/U-space convergence

The goal here is to define the TBO concept and requirements for drones to operate in U-space, interoperable with TBO in ATM. This concept is necessary to facilitate their access and operations in controlled airspace, and requires the development of separation standards for drones/drones and drones/manned aircraft, supported by procedures and performance-based requirements. In addition, there is a need to identify requirements for a U-space secured digital backbone interoperable with SWIM. The specificity of drones on account of their remote control has to be explored, identifying both for nominal and emergency conditions the way in which TBO and appropriate connectivity to SWIM can be safely assured, also taking into account the ground system and associated operational procedures.

> By 2025, enhanced integration/revisions of 4D trajectory in the execution phase are developed to support the implementation of the concept of TBOat global level.
>
> By 2025, EPP elements are integrated into the Network Manager systems for improvement of post-departure trajectory prediction.
>
> By 2030, integrated 4D trajectory automation is developed to support ATM/U-space convergence towards the TBO concept. By 2030, enhanced integration/revisions of 4D trajectory in the execution phase is demonstrated to support the full concept of TBO.

Single-pilot operations (SPO)

A significant move from current aircraft with two pilots to a single crew in the cockpit, i.e. single-pilot operations is being investigated. SPO as opposed to fully automated flight respects the societal expectations to have a human in the cockpit for strategic decision making while increased automation enables automatic flight phases.

> By 2035, the SPO with a limited level of autonomy are deployed for short range aircraft categories (e.g. category C), while progressive autonomy functions and aircraft categories extension are envisaged a few years later.

A precondition for success is the ability to have a demonstrator by the end of 2027 in close cooperation with EASA.

In order to operate safely with a reduced crew, safety systems and crew health monitoring systems will be a key enabler to trigger the back-up modes in case of incapacitation, stress or exhaustion of crew members. This is of paramount importance in order to be able to recognise possible dangerous situations, forgotten steps of procedures or check lists, inappropriate or non-executed actions by the pilot.

There is a need to demonstrate the integration of a safety-critical autonomy platform, with an extended high-integrity flight control platform hosting time and safety critical functions, as well as flight control utilities and autonomous back-up mode, which will be developed outside of this SRIA (e.g. Clean Aviation, CORAC, etc.).

Following an assessment of the roles of ground and air actors, both in normal and abnormal conditions, in the context of SPO supported by a digital assistant, the following topics should be addressed:

- Safe return to land: conditions under which pilot incapacitation is declared and how it is handled by the various actors involved, definition of ground assistant role when the pilot is in command, the definition of incapacitation declaration and management procedures, between aircraft, the airline operation centre and ATM.
- FOC-WOC/ATC connectivity: the expected role of FOC/WOC in the case of SPO abnormal situations requires their connection to ATC centres to support safe return to land even in a congested traffic environment.

Integration of drones in all classes of airspace (IFR and VFR)

The Digital European Sky builds on the evolution of ATM towards the integration of drones, from small vehicles that are mainly operating at very low level (VLL) close to urban areas and airports, up to large vehicles, such as remotely-piloted aircraft systems (RPAS), used both for civil and military applications, which will routinely operate safely using ATM services: manned and unmanned should be able to use the same airport infrastructure; they will both communicate with ATC using datalink; rules and procedures will be applied to both, with some adaptations for drones as the pilot is on the ground.

> By 2040, the integration of cargo drones into all classes of airspace will significantly improve the cost efficiency of the transportation of goods within Europe and overseas.

The research will look at:

- How to enable drones to operate in controlled/uncontrolled airspace, both under IFR or VFR, and safely integrate with cooperative and non-cooperative traffic
- How to ensure that airborne safety nets will remain effective and independent from separation provision while possibly adapting ground-based safety nets to these new modes of separation.

Super-high-altitude operating aerial vehicles

These vehicles, which can be viewed as drones, will also need to be integrated, with entry and exit procedures through segregated or non-segregated airspace. As a result, new airspace users include highly autonomous vehicles. Safe separation management of this traffic and efficient integration into the traditional ATM operation is both a technical and operational challenge.

> By 2035, daily high level operations (HLO) are expected and their transition from a segregated and/or non-segregated airspace have to be well established with appropriate regulations (with EASA involvement), clear technological capabilities and suitable performances for such air platforms.

Moreover, airborne surveillance and the safety nets (terrain, weather, traffic) and evasive manoeuvres will certainly be impacted by the introduction of new vehicles, such as drones (evolving in lower airspace below 500 ft.).

DEPENDENCIES WITH OTHER INITIATIVES IF REQUIRED

- The French Conseil pour la Recherche Aéronautique Civile (CORAC) has launched work on the route to autonomy.
- The ICAO Global Air Navigation Plan calls for 4D TBO worldwide and FF-ICE for all classes of airspace and types of aircraft.
- SESAR exploratory research project for SPO (SafeLand)
- NASA has launched research on autonomous flight rules (AFR)

EXPECTED HIGH-LEVEL OUTCOMES AND PERFORMANCE OBJECTIVES

The air-ground integration supported by automation levels 2/3 then 4/5 (see Figure 4) will enable the implementation of target architecture and transformation to TBO (phases C&D). In particular, the integration of certified drones into all classes of airspace will be achieved thanks to increased automation and delegation of separation responsibility to systems. In addition to full U-space services, single pilot operations will be rendered possible.

The qualitative assessment below is to be read as the contribution of the air-ground integration and autonomy elements to the overall performance benefits brought about by the related enablers/capabilities.

EXPECTED HIGH-LEVEL OUTCOMES AND PERFORMANCE OBJECTIVES (CONT'D)

Environment (+)	Optimised operations due to integrated 4D trajectory operations contribute to the related optimisation of fuel-burn and therefore of CO_2 emissions per flight.
Capacity (=)	The main objective of the integration is to maintain capacity even with important changes in the respective fleets, i.e., manned versus unmanned, HLO impacting the density of crossed airspace below.
Cost efficiency (+)	Airspace users: SPO can be seen as a significant benefit for airspace users. Ground ANSPs: With the new services supported by ground-ground and air-ground connectivity, cost efficiency is expected to be improved.
Operational efficiency (+)	Operational efficiency will be improved thanks to advanced communication means (including agile frequency transfer, system to system dialogues) and increased automation (reduced workload for ATCOs and flight crews/remote pilots) Horizontal flight efficiency will be improved in SESAR2020. Trajectory management will provide further improvements in vertical flight efficiency and cruising/taxiing fuel consumption when flights are subject to queuing.
Safety (+)	Operational safety is positively impacted by the design of new operations providing advanced separation management and collision avoidance for all aircraft. Autonomy enables the human actors to be discharged from routine tasks and to focus on strategic tasks, including safety oversight of the operations.
Security (=)	The increased connectivity between stakeholders could have a negative impact on the security of the system including multi-threats. This will be compensated for by the research initiatives included in other sections of the agenda.
Civil-military coordination (+)	The integration of 4D trajectories either civil (business) or military (mission) via the coordination of sharable data among stakeholders (NM, FOC, WOC, ATC) will enable to accommodate all types of aircraft in the TBO concept.

ROADMAP 2 – AIR-GROUND INTEGRATION AND AUTONOMY

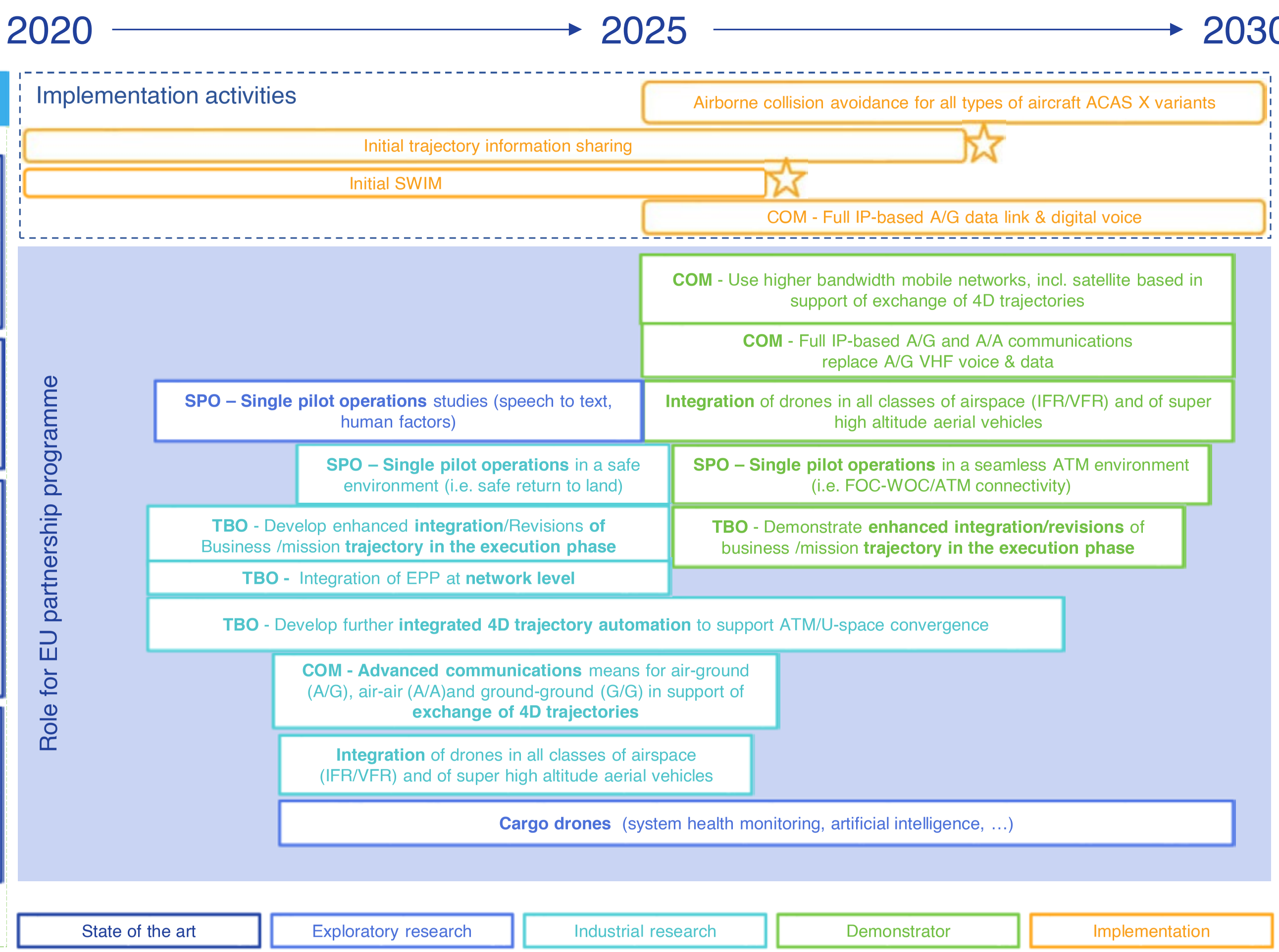
State of the art

- Independent rotorcraft operations at airports
- Enhanced rotorcraft and general aviation (GA) operations in the TMA
- Surface operations by remotely-piloted drones

- Initial SWIM: flight & meteorological information exchange
- SWIM infrastructure and profiles: purple profile for air-ground advisory exchanges

- Initial trajectory information Sharing (i4D) extended projected profile (EPP) availability on the ground
- ATC planned, tactical and NM trajectory performance improvement
- eFPL supporting shared business trajectory (SBT) transition to reference business trajectory (RBT)

- Development of new services to support ADS-B solutions for GA
- Airborne collision avoidance for all types of aircraft (ACAS X)
- Future communication infrastructure (SATCOM & LDACS) strategy



Vision

Advances in technologies and capabilities for new unmanned aerial vehicles will pave the way **for higher levels of airborne automation,** enabled by the development of a framework for **the integration and management of drones alongside manned aviation operations**.

Airframes for commercial passenger transport will move from the current large aircraft with two crew members to a single crew member in the cockpit (**single-pilot operations - SPO**), paving the way for fully autonomous flights.

TBO concept will enable airspace users to operate their preferred trajectory from gate to gate, in order to satisfy their needs, through **4D trajectory optimisation** during the planning and execution phases. By optimising aircraft trajectories TBO will bring increased predictability, enabling a reduction in buffers and optimisation, and support greater fuel efficiency. Its benefits will be further increased when combined with solutions such as continuous descent and climb, which will reduce both emissions and noise.

Source: SESAR 2020 PJ.20 (W2) project partners

3.3 CAPACITY-ON-DEMAND AND DYNAMIC AIRSPACE

PROBLEM STATEMENT

For the last decades, capacity has not been available when and where needed and it has often been available when and where not needed. New airspace users including RPAS/HAO traffic will increase by 2030 and will require an increased level of capacity and its variability.

Integrated Air Traffic Management- requires agility and flexibility in providing capacity where and when it is needed, particularly for maximising the use and performance of limited resources, i.e. airspace and ATCOs. It will require the dynamic reconfiguration of resources and new capacity-on-demand services to maintain safe, resilient, smooth and efficient air transport operations while allowing for the optimisation of trajectories even at busy periods.

DESCRIPTION OF HIGH-LEVEL R&I NEEDS/ CHALLENGES

On-demand air traffic services

In the future, the increasing number of flights and emerging new technologies will lead to a structural transformation of the way air traffic services are provided. Delivering the capacity needed across the network, improving cost and flight efficiency while maintaining safety and resilience requires the supply to be optimised on demand in a dynamic, agile and resilient manner.

The challenges of providing capacity on demand are:

- Ensuring that automation using artificial intelligence supports ATCOs and is under their supervision.
- Adapting training programmes for ATCOs and other ATM personnel in order to manage an increased level of automation. The management style should ensure the transparency of automated processes to humans and the capability of human interventions only when necessary.
- Addressing legislation, certification and social dialogue issues.
- Offering an increased level of capacity, while accepting a much higher level of complexity so that optimised flight efficient trajectories do not result in structural limitations on capacity.
- Offering increased levels of capacity and flexibility to allow capacity variations in time and space to meet levels of demand.
- Offering airspace users at all times the most environmentally friendly options when there is the need to constrain traffic, particularly when queueing aircraft at the arrival or departing runways - so that holding no longer exists as part of normal operations and, if and when there is the need for conflict resolutions, offering real-time options to airspace users so that they can select the least penalising trajectory.
- Establishing a network performance cockpit for "network minded" decision-making including support to enhanced connectivity both for identifying unattended business opportunities and for managing disruptive crises.

The capacity-on-demand concept aims at flexibly allocating resources to where they are required due to traffic demand, irrespective of the controller's physical location in Europe, while taking into account network optimisation needs. It also requires standardised data sharing between air traffic service providers using a highly interconnected and resilient network.

- Dynamic airspace management and airspace configurations (DAC): Improvement of airspace utilisation is obtained through flexibility in airspace organisation and design, and flexibility and agility in airspace management. DACs are used to accommodate specific civil and military demands. DACs integration into air traffic flow and capacity management (ATFCM) will contribute to the collaborative optimisation of traffic flows. Airspace management configuration should accommodate traffic demand and military operations, resolving complexity issues and balancing workload and optimising resources, using digital services (e.g. Machine learning to identify and exploit information patterns, and artificial intelligence to identify and design new elementary basic sector volumes). Potential changes to ATCO licences and training will need to be researched, including the use of conflict detection and resolution support tools by ATCOs in order to ensure capacity growth, against a trend of creating smaller sectors where capacity benefits reach a finite limit. The challenge for DAC is to join airspace management (ASM) and ATFCM into a single "rolling" planning process, while optimising airspace resource utilisation and fully linking to performance targets.

- Dynamic mobile areas (DMA2 and 3): DMAs will support the dynamic configuration of segregated airspace and management of mission trajectories, thus contributing to the efficiency of both civil and military operations. The areas will have a potential to "roll up" following use over time, distance and volume as a mission progresses allowing for the early release of airspace for other users.
- Dynamic extended TMA (including procedures and systems to enable continuous climb operations - CCO and continuous descent operations - CDO): TMA operations will benefit from the capability to dynamically extend the scope of terminal airspace, bringing improved flight efficiency. This will further optimise the application of advanced continuous climb and descent operations and will improve descent and climb and the synchronisation of arrival/departure flows.
- Flow-centric approach including the full reconciliation of ATFCM measures with other measures/advisory and multiple constraint manager: Network operations will be further enhanced by the optimisation of multiple ATFCM demand measures while reducing the adverse impact of multiple regulations affecting the same flight or flows. Indeed, for the provision of common network situation awareness and enhanced demand and capacity balancing, network management will gradually evolve towards flow-centric operations. This will enable a collaborative approach in the context of flow and network management for increased dynamic capabilities and predictability, leading to the capacity-on-demand concept.
- Digital integrated network management and ATC planning (INAP): In order to cover the planning gap between ATFCM and ATC processes and facilitate layered ATM planning in the execution phase, integrated network management and ATC Planning (INAP) will be gradually implemented to optimise the flow management process. Digital platforms would aim to expand the what-else concept e.g. the system suggests alternatives or refinements based on the initial solution proposal by the operator. AI and automation is still to be researched while the INAP CONOPS is already clear now. Within INAP there is also the need to research spot management, which uses traffic monitoring values (TMV), standing for different objectives (safety, rate optimisation, critical and crisis situations, etc.) to define and address different types of spots (regions of interest). For instance, local spots need to be integrated (in terms of information-sharing and operational procedures) with the Network Manager's NetSpot.
- The network integration of higher airspace operations (HAO) (FL500 and above): There is a need to ensure the integration of these operations as they transit through the classic European ATM Network. Indeed the current Network and higher airspace should be seen as a continuum requiring research and eventually demonstrations to confirm the services required by new airspace users, notably high altitude long endurance (HALEs) platforms, sub-orbital and commercial space operations, supersonic and eventually hypersonic passenger transport. Challenges exist in how to integrate new entrants with their diverse performance transiting through the classical ATM network as well as determining services required in HAO. Moreover, these HAO challenges and services' definition require extra-European coordination. Some examples:
  - To transform some European airports into spaceports (designated and authorised site for launch/take-off and/or re-entry/landing of sub-orbital vehicles).
  - The use of non-cooperative tracking of a high-altitude vehicle: it could be continuously carried out in real time in order to monitor the vehicle's status, the flight path and to enable the prediction of the vehicle's position or debris excursion in case of a mishap.
- RPAS demonstration for RPAS accommodation in controlled airspace (Airspace Class A to C): This key R&I activity is aimed at accommodating IFR RPAS in non-segregated airspace in accordance with the drone roadmap in the European ATM Master Plan. The objective is to enable IFR RPAS operating from dedicated airfields to routinely operate in airspace classes A-C as general air traffic (GAT) without a chase plane escort. The scope includes development of adaptations to the flight planning processes, DCB developments, contingency, etc.

ATM continuity of service despite disruption

In case of disruption, the new airspace architecture should enable solutions allowing for continuity of service. For example, it should enable resources (including data) to be shared across the network supporting flexible and seamless civil/military coordination allowing for more scalable and resilient service delivery to all airspace users. Resilient ATM systems would continue to provide services despite disruption, e.g. during capacity bottlenecks, adverse weather, national system breakdowns or disruptive social actions.

- Reconfiguration/Consolidation of x-border dynamic and remote air traffic services (ATS): Operational plans need to include flexible and dynamic sectorisation by taking into account basic complexity indicators based on specific shapes of demand, network flight efficiency needs plus existing ATC technology enabled capabilities and the application of the virtual centre concept. A new notion of area control centres (ACCs) with multiple areas of responsibility (AoRs) will provide remote ATS capability. This can lead to the need for local/regional plans for cross-border sectorisation and consolidation/reconfiguration, in particular for the upper airspace sectors, in a dynamic manner.
- Training and licensing of ATCOs: An assessment is required of the level of new training and licencing needed for new cross-border dynamic sectors and remote ATS operations where sector families or traffic flows may be new to ATCOs.
- Training and competency requirements for ATM personnel contributing to the cross border ATM/ANS service delivery as enablers of technical reconfiguration for remote ATS operations.

Future data services and applications for airport and network

Future data services and applications commence with User-driven prioritisation process (UDPP), which provides airspace users with more control over the selection of flights which are delayed in order to prioritise them based on business needs, and which can gradually be extended to new ATFCM rules and queueing techniques.

- Integrated UDPP (including links with ATFCM slot swapping) will demonstrate the application of airspace user priorities and preferences in the establishment of ATFCM measures and support to airspace users to ensure the maximum throughput of payload factor

when subject to heavy flow management restrictions and in a crisis period (e.g. terminal overloaded with passengers during periods of dramatic airport capacity reduction). Also, the demonstration of UDPP concept applicability to other operational environments in the planning phase (en-route constraints, use in nominal situations, etc.…) is required.

- In terms of development, support to airspace users is required on the definition and validation of new operational and social indicators. These should be integrated into the overall R&I performance framework, building on the results of SESAR validations, identification of gaps and development of steps from research to pre-industrialisation and deployment (full integration of operational processes and systems' interoperability).
- The integration of connectivity within the loop of ATM operations, the new data sets available through A-CDM, UDPP, AOP/NOP data, TTO/TTA and extended AMAN demand further development of the rules for ATFCM and queuing priorities. This will require further exploratory research.

Demonstrations are expected to play a critical role in closing the industrialisation gap, as they can potentially act as a platform that accelerates the creation of a critical mass of early movers to complete pre-implementation activities, maximising the chances of speeding up the time to market and operational uptake throughout the Network.

DEPENDENCIES WITH OTHER INITIATIVES IF REQUIRED

- Connected and automated ATM are the basic elements to ensure the operational capacity changes described in this section.
- A high-level of ATCO productivity and the scaling up or down of capacity does not depend solely on DAC and INAP, but also on the virtualisation and availability of ADSP and TBO data.
- Air-ground and ground-ground integration is fundamental to delivering TBO and taxi-routing optimisation.
- Green operations of the European Partnership for Clean Aviation.
- Airport operating environment and multimodal transport concepts will also influence capacity-on-demand.

EXPECTED HIGH-LEVEL OUTCOMES AND PERFORMANCE OBJECTIVES

By providing capacity dynamically where and when it is needed and re-configuring the airspace to match the traffic flows, overall system resilience and flexibility are increased significantly. Predictability (from an airline and airport scheduling perspective) is ensured by a more stable and predictable level of capacity in all-weather operations.

Peak runway throughput increases could deliver improved exploitation of the airport in terms of both airport slot increases (in the scheduling phase) and on-time operations.

The optimisation of trajectories helps to reduce fuel burn and increases predictability, contributing as such to flight efficiency, reducing the environmental impact and enhancing the passenger experience.

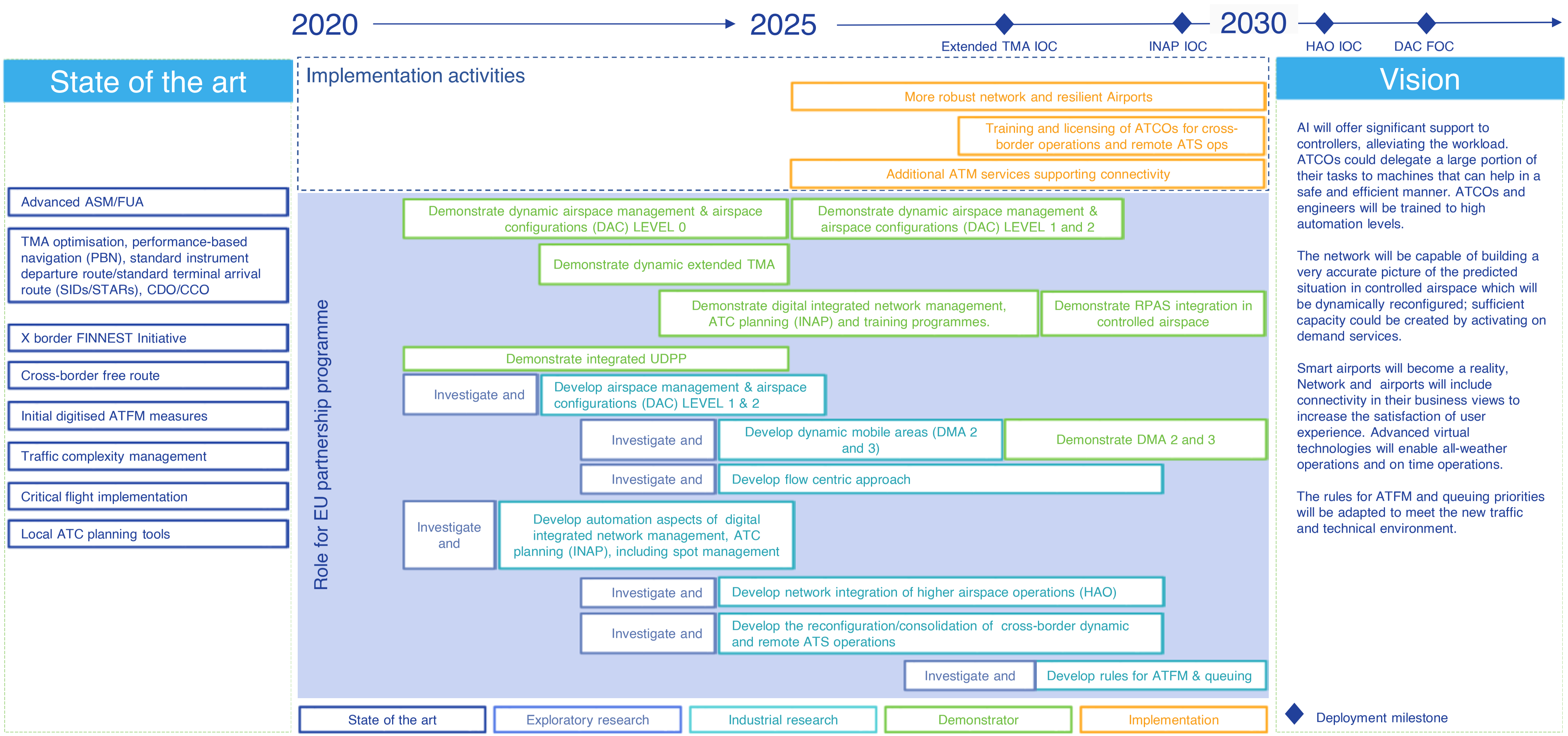
The establishment of the common network performance cockpit, following the definition of appropriate key performance areas (KPAs) for the performance of the airspace, will allow an increased level of connectivity providing new opportunities for revenue generation and the creation of new opportunities for business between European regions.

An increased level of ATCO productivity will make it possible to manage traffic growth with the current level of resources, thus improving cost efficiency.

EXPECTED HIGH-LEVEL OUTCOMES AND PERFORMANCE OBJECTIVES (CONT'D)

	Environment (+)	More precise trajectories in arrival and departure will reduce the noise impact and so airline costs in terms of paying noise penalties.
	Capacity (+)	Capacity is measured in terms of either ATFM delays (lack of capacity) or throughput. The en-route capacity aims to maintain ATFM delays at 0.5 min/flight or less. TMA and peak runway throughput shall be increased according to traffic forecasts. A more stable and predictable level of capacity will be achieved in all-weather operations. In addition, by providing capacity dynamically where and when it is needed and re-configuring the airspace to match the traffic flows, overall system resilience will be significantly increased.
	Cost efficiency (+)	DAC, capacity-on-demand, ATCO training programmes will provide scalability. ATCO productivity is expected to increase significantly.
	Operational efficiency (+)	Trajectory management and DAC will provide further improvements in vertical flight efficiency and cruising/taxiing fuel consumption when flights are subject to queueing. Overall improvements in capacity and trajectory management and DAC are expected to reduce the average delay in block to block times by 4 minutes per flight.
	Safety (=)	Safety levels are maintained.

ROADMAP 3 – CAPACITY ON DEMAND AND DYNAMIC AIRSPACE



Source: SESAR 2020 PJ.20 (W2) project partners

3.4 U-SPACE AND URBAN AIR MOBILITY

PROBLEM STATEMENT

Over the next 10 years, the implementation of this SRIA aims to unlock the potential of the drone economy and enable urban air mobility (UAM) on a wide scale. To that end, a new air traffic management concept for low-altitude operations needs to be put in place to cater safely for the unprecedented complexity and high volume of the operations that are expected. This concept, referred to as U-space, will include new digital services and operational procedures and its development has already started within the SESAR 2020 programme. U-space is expected to provide the means to manage safely and efficiently high-density traffic at low altitudes involving heterogeneous vehicles (small unmanned aerial vehicles, electric vertical take-off and landing – eVTOLs - and conventional manned aircraft), including operations over populated areas and within controlled airspace. U-space will have to integrate seamlessly with the ATM system to ensure safe and fair access to airspace for all airspace users, including UAM flights departing from airports.

DESCRIPTION OF HIGH-LEVEL R&I NEEDS/ CHALLENGES

The development of U-space will have to overcome extraordinary challenges. A new regulatory framework, supported by a comprehensive set of standards, has to be established to provide a solid framework for safety and interoperability without hindering innovation. U-space will have to integrate seamlessly with the ATM system to ensure safe and fair access to airspace for all airspace users. This integration will not be straightforward since the requirements on U-space services may not be compatible with those imposed on ATM. To cater for the anticipated volume of operations, U-space will need to rely heavily on automation and to take advantage effectively of emerging on-board capabilities and advanced digital technologies on the ground. In addition, U-space is expected to have a profound socio-economic impact, enabling the creation of a new marketplace for U-space service provision and accelerating the advent of the drone and urban air mobility economy. Ultimately, the development and deployment of U-space will help position Europe as the global leader in UAM and drone-based services, accelerating the development and adoption of new technologies (AI, cloud, digital services, big data) and fostering the creation of high quality jobs.

U-space provides an unparalleled opportunity to experiment, test and validate some of the key architectural principles and technology enablers of the future Digital European Sky before incorporating them into the broader ATM ecosystem. It can potentially help de-risk and accelerate the digital transformation of the European ATM system while opening the way to the safe integration of new vehicles into the airspace. UAM is expected to be the most challenging type of operations supported by U-space. UAM will enable on demand highly automated operations of drones and larger eVTOL vehicles over urban areas, providing cargo, emergency and passenger transportation. Plans are afoot to deploy UAM in many European cities, with small-scale cargo operations already taking place and initial passenger services expected to launch by 2025. UAM will involve new types of vehicles with heterogeneous performances and high levels of autonomy, which will have to coexist with conventional manned traffic and will need to be accommodated by the U-space and ATM ecosystems.

Considering the above, the main research and innovation challenges required to deploy U-space will include the following:

- **Mature, validate and deploy across Europe the basic U-space services**: The set of U-space services has been divided into 4 levels (U1 – U4) of increasing sophistication and complexity [27]: U1, which includes services such as registration, remote identification and geo-fencing; U2, which encompasses services such as flight planning, flight approval, tracking, and the interface with conventional air traffic control; U3, with advanced services supporting more complex operations in dense areas, such as traffic prediction and capacity management as well as assistance for conflict detection and resolution (automated detect and avoid functionalities); and U4, with services still to be defined that will support high levels of autonomy and connectivity as well as integration with manned aviation and ATM.

Although descriptions of many services exist at U1, U2 and even U3 levels, and a concept of operations (ConOps) shows how they can fit together, work is still needed on validation, cost benefit analysis and standardisation. Although different U-space architectures have been proposed, work is still required to assess different options and identify those that meet the full range of requirements by the different types of operations and guarantee safe and secure interoperability, thereby enabling a pan-European competitive environment for the provision of U-space services. One of the challenges is to enable the simultaneous operations of multiple U-space service providers (USSP) in the same airspace. In addition to the definition of potential U-space architectures, preliminary implementations of U1 and U2 services have already been demonstrated in the SESAR 2020 programme. Eurocontrol is collecting data from States to assess their progress towards deployment (as part of the EU Network of U-space demonstrators initiative, led by the EC), which has so far been limited. Many questions still need to be answered before full-scale deployment is feasible, particularly in the areas of interoperability, certification and performance requirements, safety and security, fairness, contingency management, financing and liability.

- **Develop advanced U-space services:** In parallel to the full validation, industrialisation and deployment of the basic U-space services, work needs to start on the definition, design and development of advanced services. The most advanced U-space services (U3/U4) will enable UAM missions in high-density and high-complexity areas. The required technologies to enable performance-based CNS services in U-space need to be identified and assessed in operational environments. For example, the use of mobile communication technology, such as 5G, and other emerging technologies for connectivity should be studied, as well as data link solutions to enable electronic conspicuity and surveillance. Different solutions for separation management for all types of vehicles in all types of airspace (including airborne detect and avoid (DAA) as well as ground-based and hybrid solutions) should also be considered.
- **Enable urban air mobility (UAM):** The requirements of UAM operations are expected to be the most challenging for the U-space ecosystem. One of the key research questions is how to integrate the airspace autonomous operations over populated areas safely into complex and congested airspace environments, with operations involving vehicles interacting with U-space and conventional ATM services. Research should investigate how U-space can support the transition from piloted to autonomous operations (linked to EASA AI Regulatory Roadmap[17]). The evolution of U-space together with its associated regulatory framework and standards will need to be synchronised and coordinated with the development of the future UAM ConOps, its associated UAM services and the certification of UAM vehicles. Special consideration should be given to the operational limitations of these new vehicles and how U-space can contribute to operational safety by protecting their operation in contingency and non-nominal situations. In addition, mechanisms and protocols to enable Collaborative Decision Making in the context of UAM, involving ATM, U-space and city stakeholders, will need to be explored.
- **ATM/U-space integration:** U-space services shall enable safe and efficient operations of unmanned aircraft without negatively impacting the operations of other airspace users. The seamless integration of U-space and ATM services is expected to contribute to the fairness, safety, efficiency and environmental impact of the overall air traffic system. The capacity benefits and flexibility of an airspace without segregation requires the full integration of U-space and ATM. For U-space and ATM environments to be integrated, it does not necessarily mean they operate in the same way. They could be very different indeed, but with suitable interfaces to allow safe and effective coexistence. Standard operating procedures will need to be defined (for example rules of the air and airspace management) to allow manned and unmanned aircraft to share the same airspace safely, as well as the simultaneous provision of U-space and ATM services). The safety, security, certification and regulatory challenges arising from the provision of U-space services to manned aircraft should be studied. Information exchange will be critical to enable a safe convergence of U-space and ATM. Challenges include cybersecurity, data compatibility and the reconciliation of different standards and certification requirements. Another critical aspect of the integration will be the role of the human, particularly regarding the high level of automation that will be delivered by U-space services and the automation disparity between ATM and U-space.

In addition to the key challenges described above, the following transversal research areas will be critical to the successful development and deployment of U-space.

- **Financial and legal aspects:** Research needs to be conducted on potential U-space and drone operator business models, focusing on the mechanisms required to create a fair and competitive U-space market across Europe. The available alternatives for the financing of a sustainable

U-space ecosystem should be analysed, including how to optimise public and private investments and the implications for the financial model of European ANSPs. The insurance models required for U-space should also be analysed.

- **Social acceptance:** Work is required to ensure that the new operations enabled by U-space are acceptable to the public. Specific areas of concern will be UAM noise, visual pollution, privacy, etc. In addition, a consensus must be reached on the acceptable target level of safety of the different types of operations under U-space. The impact on general and leisure aviation should also be considered.
- **CNS and separation minima:** Definition and validation of performance-driven CNS requirements for operations under U-space, together with the applicable separation minima. The separation minima will be related to the CNS performance, available separation management services and other relevant criteria – ground risk, vehicle performance, etc. Validation of CNS technologies against the performance criteria.
- **Support the development of the U-space regulatory framework and required standards**: Leverage extensive modelling, simulation and experimentation to assess the maturity and interoperability of U-space services, assess different deployment options and support their industrialisation and deployment. Create U-space test centres offering an environment for stakeholders to conduct reproducible and interoperable tests in conditions comparable to live operational scenarios, with the objective of validating standards and regulations in representative environments. Such centres can also support the certification of new U-space service providers, services or technologies, making it possible to increase flexibility for rapid and agile increments of the U-space ecosystem.
- **Transfer of U-space automation technology to ATM**: Explore whether U-space can be an accelerator of the ATM innovation life cycle, facilitating faster, lower risk adoption of new technologies or approaches (automation, AI, cloud, etc.).
- **U-space performance framework:** A performance framework for U-space needs to be defined in concordance with the overall SES performance framework, so as to assess and guide the deployment process based on objective and quantifiable performance measurements.
- **Safety assurance:** New safety modelling and assessment methodologies applicable to U-space are needed. Tools are required to analyse and quantify the level of safety of U-space operations involving high levels of automation and autono-

my, where multiple actors automatically make complex, interrelated decisions under uncertainty (e.g. weather-related uncertainty). Research is needed to ensure that the distributed decision-making protocols implemented in U-space achieve the required level of safety while catering for differing levels of experience of participants. Examples of approaches that could be leveraged for this purpose include greater use of simulation and machine learning applications such as stress-testing.

- **Applications above VLL airspace:** Explore potential applications and extensions of U-space concepts beyond VLL airspace, for example to support manned traffic in uncontrolled airspace or to enable high altitude operations.

DEPENDENCIES WITH OTHER INITIATIVES IF REQUIRED

- Clean Aviation partnership
- EASA certification of UAM vehicles (airborne / ground requirements) - EASA AI Roadmap
- EASA U-space Regulatory Framework development (EASA opinion 01/2020 and its successors)
- AW-Drones (**https://www.aw-drones.eu/**). Horizon 2020 Research and Innovation Programme to provide guidance for the harmonisation of standards to support future EU drone regulation
- ICAO GANP and ICAO UTM Framework Document
- European Network of U-space Demonstrators
- SESAR 2020 Project PJ34 on ATM-U-space integration
- SESAR 2020 exploratory research projects on U-space services (DACUS, BUBBLES, etc.) and SESAR 2020 VLDs on U-space for UAM
- Initiatives addressing UAM ConOps definition and implementation, such as the research projects in response to the call H2020-MG-2020 "Towards sustainable UAM"
- NASA National Campaign on Advanced Air Mobility
- UAM OEM's development and certification activities
- National and international U-space/UTM/UAM implementation programmes
- Ongoing work by standardisation bodies, such as ASD-STAN, EUROCAE and ASTM.
- European innovation partnership on smart cities and communities (EIP-SCC)
- Multimodality and passenger experience activities within iATM

EXPECTED HIGH-LEVEL OUTCOMES AND PERFORMANCE OBJECTIVES

The assumption made in the European ATM Master Plan 2020 edition is that the coordinated development and deployment of U-space is key to realising in a timely manner the economic benefits anticipated in the 2016 Drones Outlook Study. In addition, the assumption is that U-space will not have a negative effect on the Master Plan performance ambitions for the European ATM system. This holds specifically true for the ambitions relating safety, security, and capacity (notably, at airports) and cost efficiency.

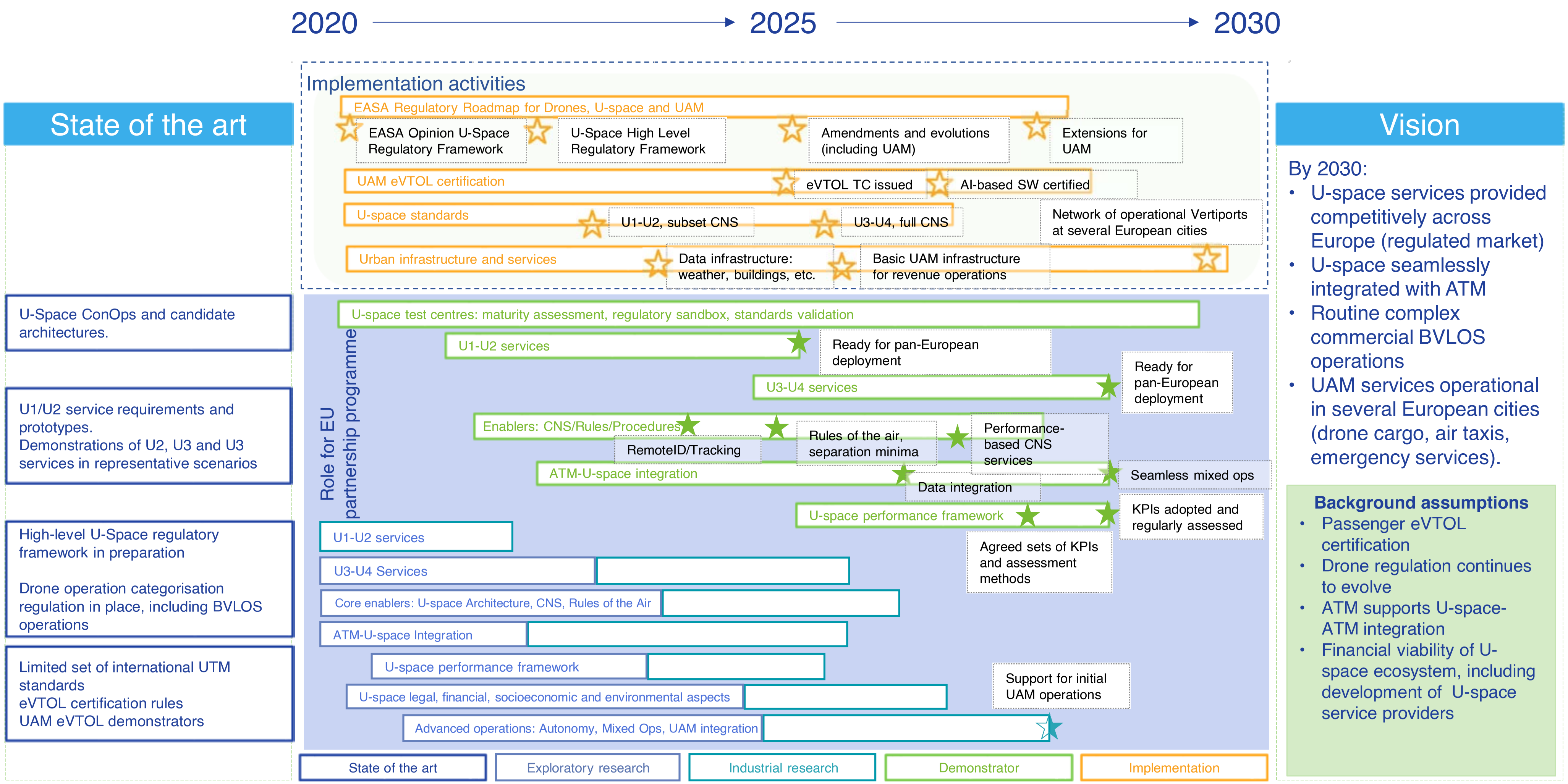
Specific performance metrics for measuring the efficiency of U-space service provision need to be developed as part of the U-space R&I and will result in a specific U-space performance framework. This will not only ensure that U-space service provisions can be properly evaluated but will also enable an assessment of the additional benefits obtained through the coordinated development of such services.

An initial qualitative assessment of the expected impact of the deployment of U-space in some of the KPAs is outlined in the table below.

EXPECTED HIGH-LEVEL OUTCOMES AND PERFORMANCE OBJECTIVES (CONT'D)

Environment (=)	U-space shall not increase the environmental footprint of the air transportation system. Specific metrics will be defined, tailored to the U-space environment and the types of vehicles operating within it (most of them are expected to be zero emissions aircraft). Special consideration should be given to the noise impact of low-level operations enabled by U-space. The growing use of zero-emission UAVs enabled by U-space may also contribute to reducing the environmental footprint of the overall transportation system, for example by reducing road traffic levels.
Passenger experience (+)	In terms of passenger experience and overall socio-economic contribution, U-space will enable and accelerate the drone economy, opening the way to new services (delivery, inspection, security, UAM, etc.) that will increase the wellbeing of European citizens. U-space will foster the development of a new high-tech economic sector in Europe, leading to wealth and job creation. Particular attention must, however, be paid to safeguarding privacy and ensuring social acceptance.
Capacity (+)	U-space shall not negatively affect the capacity of the ATM system and will enable additional system capacity by enabling large volumes of unmanned aircraft to access the airspace. Specific capacity metrics shall be defined for U-space defined in terms of safety or other concerns such as noise.
Cost efficiency (=)	U-space shall not negatively affect the cost of providing ATM services. Specific cost-efficiency metrics shall be defined for U-space, focusing on the cost of delivering U-space services.
Operational efficiency (+)	U-space shall substantially reduce the costs of operating unmanned aircraft in the European airspace and will not negatively affect the operating costs of other airspace users. Specific operational efficiency metrics shall be defined for U-space, including fairness aspects.
Safety (=)	U-space shall not negatively affect the safety of the ATM system. Specific safety metrics shall be defined for U-space.
Security (=)	U-space shall not negatively affect the security of the ATM system. Cybersecurity will be a key area to consider in U-space, especially regarding the interaction (data exchange) between U-space services and ATM systems.

ROADMAP 4 – U-SPACE AND URBAN AIR MOBILITY



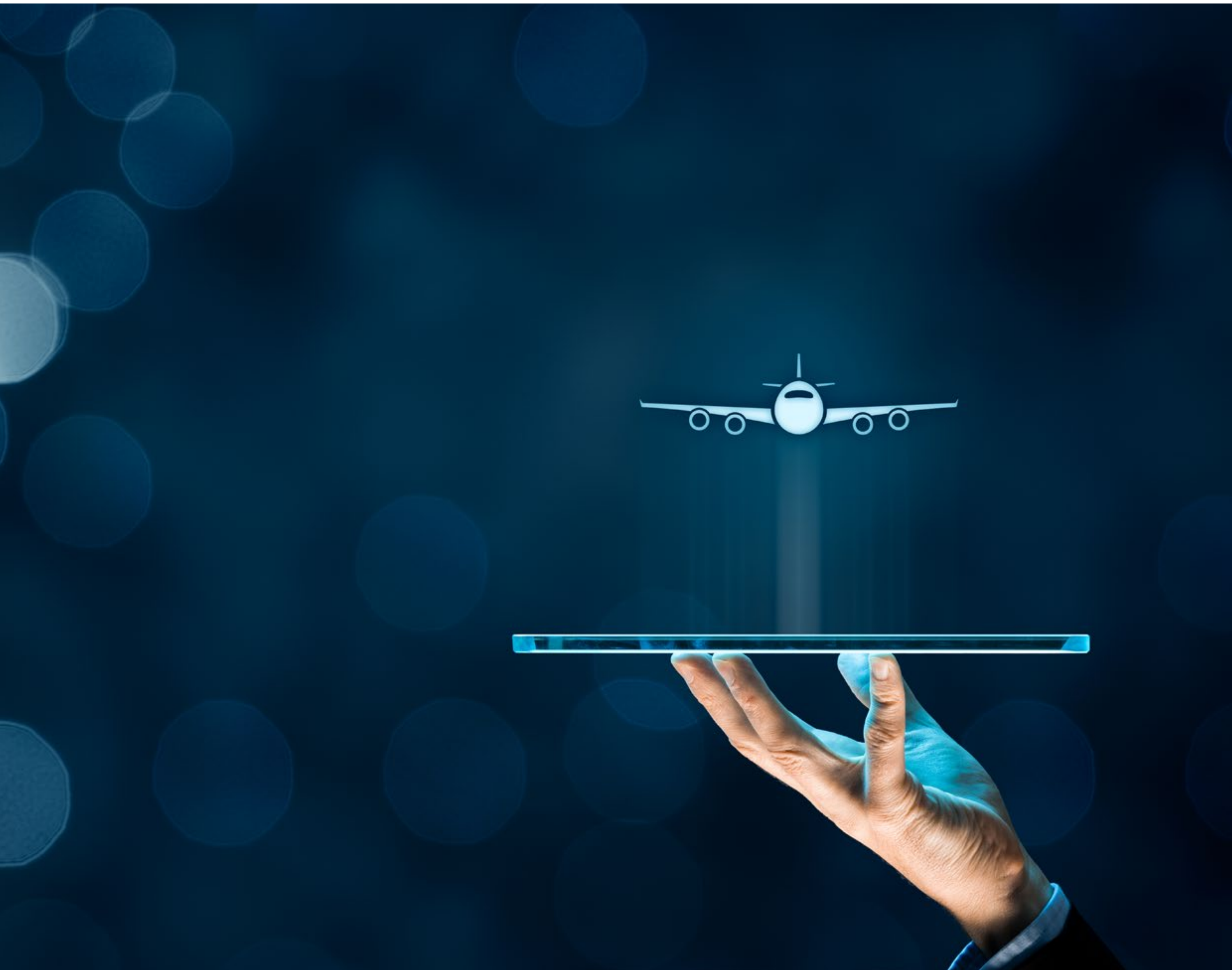
Source: SESAR 2020 PJ.20 (W2) project partners

3.5 VIRTUALISATION AND CYBER-SECURE DATA SHARING

PROBLEM STATEMENT

The Airspace Architecture Study (AAS)[11] clearly highlighted the lack of flexibility in the sector configuration capabilities at pan-European level. This is caused by the close coupling of ATM service provision to the ATS systems and operational procedures, preventing air traffic from making use of cloud-based data service provision.

A more flexible use of external data services, considering data properties and access rights, would allow the infrastructure to be rationalised, reducing the related costs. It will enable data-sharing, foster a more dynamic airspace management and ATM service provision, allowing air traffic service units (ATSU) to improve capacity in portions of airspace where traffic demand exceeds the available capacity. It furthermore offers options for the contingency of operations and the resilience of ATM service provision.



DESCRIPTION OF HIGH-LEVEL R&I NEEDS/ CHALLENGES

The particular challenges can be linked to the following key elements for delegating service provision throughout Europe:

Future data-sharing service delivery model

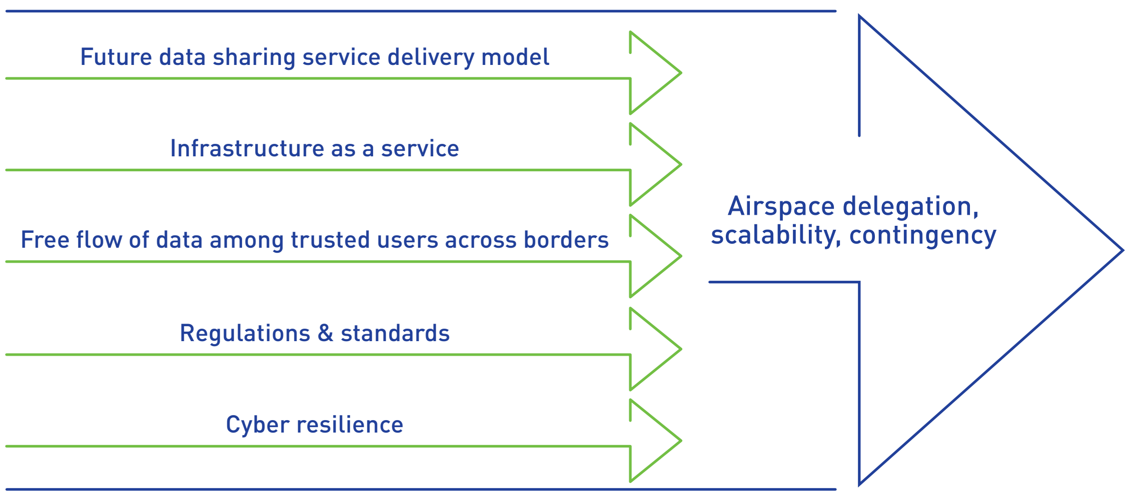
Data-sharing supports the progressive shift to a new service delivery model for ATM data, through the establishment of dedicated ADSPs. A common EU-wide ATM data service layer, will enable all ATM service providers to benefit from the cross-border sharing of data. The ADSP would provide the data and specific applications (e.g. STCA, Correlation, etc.) required to provide ATM services. On the data side, the ADSP will convey CNS (e.g. radar data, flight data processing information), ATM, voice data, AIM data (static, semi-static and dynamic data) and also meteorology (MET) data. The data can be delivered in raw format or be processed to allow the delivery of services such as flight correlation, trajectory prediction, conflict detection and conflict resolution and arrival management planning and will extend to the provision of safety-net services (e.g. short-term conflict alerts - STCA, minimum safe altitude warning - MSAW, area proximity warning - APW) and on decision-making support tools as a service (providing the what-if and the what-else functions, attention guidance, etc.). At a detailed operational and technical level, the question of drawing a clear boundary between ATM services and ADS is open and will be tested through simulations and impact assessments as the concepts mature.

1. Initial data service delivery between the ADSP and the ATSU is defined and implemented in 2026. (IOC)
2. The full data services between ADSPs and ATSUs or between ADSPs are fully defined and in operation by 2028. (FOC)
3. MET and aeronautical information (AIS) services developed and implemented over SWIM IWXXM and AIXM standards.

Infrastructure as a service

Through a service-oriented architecture (SOA), the infrastructure services (e.g. communication, navigation and surveillance) will be specified through contractual relationships between customers and providers with clearly defined European-wide harmonised service-level agreements. This approach will create business opportunities for affordable services with a strong incentive for service providers to rationalise and harmonise their own infrastructure in support of nominal and contingency operations and more generally the provision of safe, efficient, cost-efficient, interoperable and standardised ATM and CNS services. A large part of the CNS services will be provided through applications using space-based sensors. With regard to communications, the transition towards an IP-based environment will enable the location-independent transmission of data and/or voice. Possibly, a dynamic allocation of IP connections will reduce the need for VHF channels on the ground side and the need for the airborne side to switch frequencies several times during the flight.

Figure 12 – KEY SERVICE DELEGATION ELEMENTS



Source: SESAR 2020 PJ.20 (W2) project partners

R&I needs to deliver solutions utilising infrastructure (CNS, IT, U-space, etc.) as a service, enabling new combined services.

1. Satellite-based navigation and surveillance functionalities are fully deployed and in service in 2026.
2. Satellite-based communications as a service with FOC in 2028.
3. IP-based environment is established to supplement the VHF communication networks.

Scalability and resilience

Open architecture guarantees the long-term upgradability and scalability of ATM service provision and the agility required to enhance services. With the delivery of ATM services irrespective of physical infrastructure or geographical location, the defragmentation of European skies can be realised through virtualisation: i.e. decoupling the provision of ATM data services from ATS, allowing them to be provided from geographically decoupled locations. Airspace capacity can be offered on demand through horizontal collaboration between the Network Manager and the ATSU. The Digital European Sky will allow for more efficient and flexible use of resources, substantially improving the cost-efficiency of service provision and delivering the capacity needed. Ultimately, the virtualisation of Air Traffic Management services will allow the creation of new business models and the emergence of new ATM players, which will foster competition in the sector. Importantly, this will enable ANSPs to make implementation choices on how new ATM services are provided. On the other hand, virtualisation will increase the need for a robust and well-proven approach to cyber resilience, including the skills and means for all human actors in the value chain to detect, respond to, and recover from complex degradation situations. The increased flexibility of the European airspace through a Dynamic Airspace Configuration makes it possible for an ATSP to cover multiple areas of responsibility (AOR) through remote ATSU provision.

In relation to section 3.3 Capacity-on-demand and dynamic airspace:

1. The relationship between the NM, the ADSPs and the ATSUs are defined by 2026.
2. ATCO licensing for dynamic location independent operations are available in 2028.
3. The Dynamic airspace management and DAC can be applied in one ATSUs, in neighbouring ATSUs or in a grouping of non-adjoining ATSUs to allow for capacity balancing.

Free flow of data among trusted users across borders

The sharing of data through interoperable platforms and, the exchange of open data between trusted partners, combined with open architecture policies, will allow improved collaboration between the different actors and the optimisation of services and processes for all partners in the aviation value chain. Such data exchange shall occur on established concepts such as SWIM and consider the associated cyber-resilience aspects.

Data will be even more critical in future and not only data-sharing but also proper data structure and storage will have to be provided. On the Network level and on the local ATM side, this will allow for big data analytics, which will pave the way for future more efficient ATM operations, thereby optimising the network at strategic level. By applying business intelligence (BI), the network could be organised in a more efficient and stable manner.

1. A Europe-based cloud infrastructure is available to support the secure exchange of data between ADSPs/ADSPs and ADSPs/ATSUs in 2026.
2. The Europe-based cloud infrastructure provides services to adjoining ATSUs beyond the EU remit by 2028.

Regulations and standards

The implementation of a SOA will have an impact on the management of performance, while potentially significantly improving capacity and cost efficiency. For this reason, the regulatory environment will need to be adapted to make way for the new ATM Service environment and must facilitate greater consideration of operating expense (OPEX) and lower capital expense (CAPEX) requirements. The charging and cost-recovery mechanisms will need to be more flexible and, on the standardisation side, common formats and exchange profiles will need to be identified to allow a supplier-independent service provision scheme

1. The changes in the regulatory environment are enacted by the beginning of the RP/4 (2025-2029)

Cyber resilience

The increase in the number of connected devices, data-sharing and common standards will lead to an increase in vulnerabilities, threats, emerging risks and the possibility of cyber-attacks. Furthermore, the threat landscape is continually changing, and new attack vectors are created at an equally fast pace. The emergence of new actors, able to disrupt or destroy critical infrastructure, presents a significant challenge for increasingly interconnected and data-reliant industries such as ATM.

The need for the efficient application of standards addressing safety, privacy and cyber resilience risks is obvious to ensure the protection of information and information systems, manage cyber-resilience risks, implement appropriate safeguards to ensure the delivery of services, identify the occurrence and continuous monitoring of cyber-resilience events, and respond to and recover from potential cyber-attacks with a proper level of reactivity.

It will also be necessary to further develop cyber-resilience guidelines and procedures for ATM, based on existing on existing guidelines and procedures from other domains (e.g. system design principles, cryptography, block chain, software-defined networking). Inclusion of specific techniques already established in other domains should be included (e.g. Blockchain). The context of the cyber-resilience needs to be focussed on a pro-active approach to the network. If the resilience remains reactive, any successful attack could lay down large parts of the EU airspace.

1. Cyber-resilience guidelines and procedures tailored to ATM are available for IOC in 2026.

DEPENDENCIES WITH OTHER INITIATIVES IF REQUIRED

The interoperability criteria on the flight object (i.e. sharing of flight data in a consistent, widely and easily available manner, subject to appropriate access controls) will need to have reached a sufficient level of maturity to allow all parties involved access to the data at any time during all the flight phases, from pre-departure to on-block.

Additional connectivity relying on controller – pilot datalink communication are available to be considered to provide a solid alternative to the VHF voice communication channels.

The establishment of a fully virtualised environment will need to be coordinated with the ATCO licensing scheme and will therefore also be people-centric. The active inclusion of the ATCO and ATSEP communities in the development phase is a prerequisite for successful implementation. Close collaboration in and input into the EU regulatory process is required so that, where necessary, the regulations can be adapted in a timely manner to allow for deployment.

The standardisation processes conducted by the European standardisation organisations (ESOs), including EUROCAE, must be launched to ensure a set of common standards.

The activities performed at European level must become a building block for the global ATM environment, hence close collaboration with ICAO is needed.

EXPECTED HIGH-LEVEL OUTCOMES AND PERFORMANCE OBJECTIVES

The maximum scope of service delivery by ADSPs covers the ATM data services (such as flight data processing) needed to realise the virtual de-fragmentation of European skies and includes the provision of AIS, MET and CNS services.

Future ATM services will rely on enhanced provision of shared data and will allow ATSU to select one or more ADSP for the data required to guarantee a safe and efficient flow of traffic.

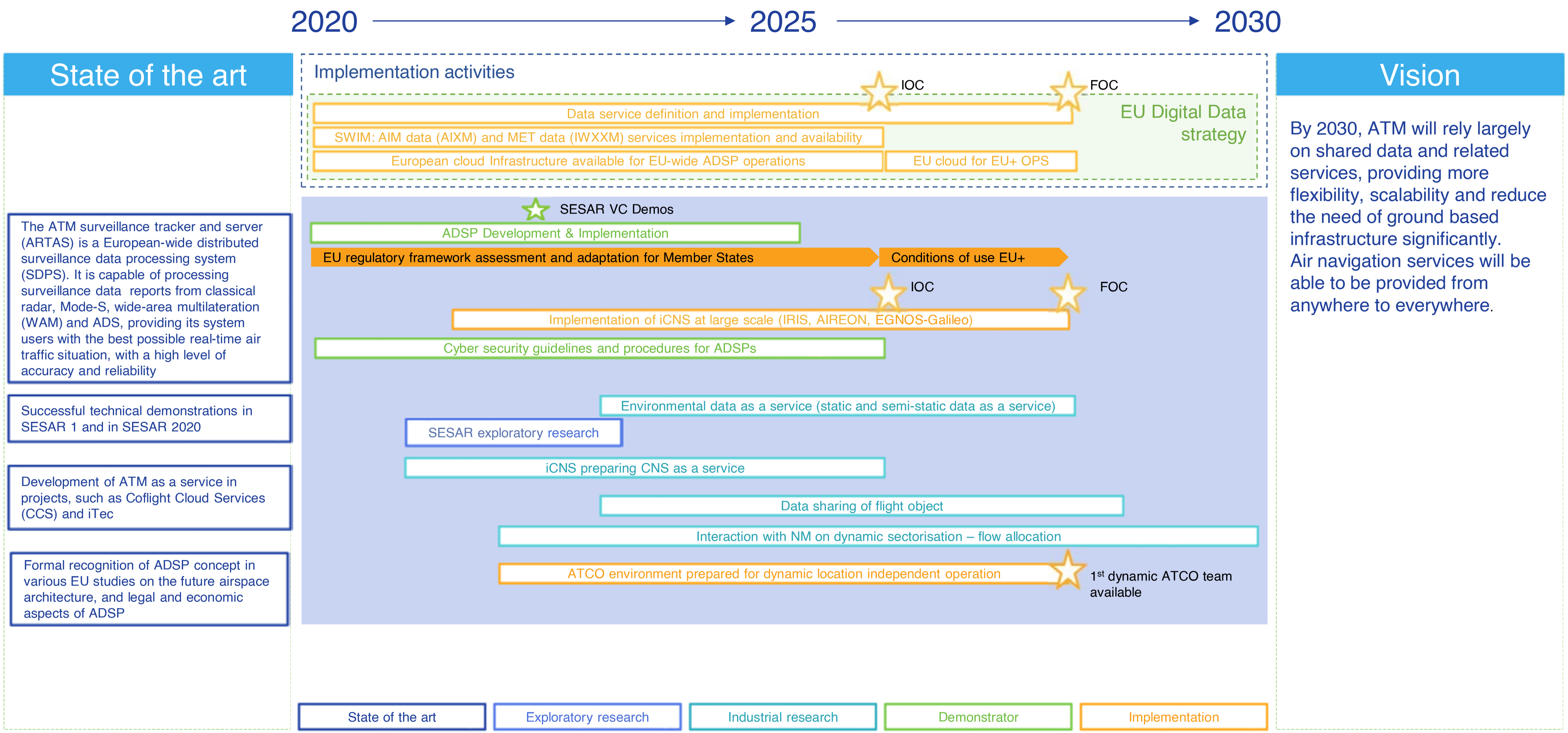
By rationalising and harmonising the ATM infrastructure, the ATM service costs will be reduced significantly. Data will no longer be produced at every ATSU and information will be shared throughout the ATM value chain and can be made available more widely to the aviation value chain, thus improving collaborative decision making (CDM) capabilities at local, regional and network level.

Data will be the key asset for future ATM service provision and will be transmitted on dedicated and secured network services.

The transition towards defragmentation will have positive impacts on the performance areas:

Environment (+)	Improved sectorisation will ensure more efficient flight routes and more optimal profiles and the reduction of delay at network level. At local level, requirements in respect of equipment and therefore power supply and cooling will be reduced.
Capacity (+)	Flexibility of sector-shifting to adapt to traffic demand and make best use of capacity at network level.
Cost efficiency (+)	Potential reduction in infrastructure and the possible creation of competition between future data suppliers will reduce costs.
Safety (=)	Safety levels will be maintained – no impact through virtualisation.

ROADMAP 5 – VIRTUALISATION AND CYBER-SECURE DATA SHARING



Source: SESAR 2020 PJ.20 (W2) project partners

3.6 MULTIMODALITY AND PASSENGER EXPERIENCE

PROBLEM STATEMENT

Flightpath 2050 [4], Europe's long-term vision document on aviation research, has set the goal that 90% of travellers within Europe should be able to complete their journey, door-to-door (D2D), within 4 hours by 2050. Optimising D2D mobility for people and goods is essential in meeting citizens' expectations for increasingly seamless mobility, where they can rely on the predictability of every planned door-to-door journey and can choose how to optimise it (shortest travel time, least cost, minimal environmental impact, etc.). The role of ATM in the door-to-door chain of a passenger's journey may seem small, but the punctuality of flights, and passengers' perception of flying, is highly dependent on the smooth functioning of the entire journey. This SRIA will, therefore, lead to an improved passenger experience by supporting an integrated transport system.

DESCRIPTION OF HIGH-LEVEL R&I NEEDS/ CHALLENGES

A significant portion of the planned D2D journey time is taken up by the buffers needed to absorb uncertainties associated with the performance of the various modes contributing to a journey (including within the airports). Mobility providers need access to reliable planning and real-time information on schedules to give more accurate forecasts of arrival and transfer times. The need to sometimes travel via a distant hub rather than fly from the nearest airport can cause a major increase in journey times and the feasibility of more point-to-point flights should be investigated, in particular the notion of thin haul (miniliners, microfeeders) as a complementary service to regional air traffic and a viable accessibility option to outreach areas as a direct enabler of 4-hour D2D travel times inside the EU. Connections through hubs obviously eliminate the possibility of 4-hour D2D travel.

Considering ATM to be an integrated part of an intermodal transport system will make it possible to share data between modes and to collaborate better to optimise the performance of both the overall transport system and the D2D journey.

These questions translate into R&I priorities associated with:

Access to /exit from the airport: Airports are obvious multimodal nodes for aviation

Real-time information exchange giving stakeholders (including mobility providers) an increased knowledge of the entire multimodal journey will enhance the reliability of multimodal journey planning, identifying potential access issues that could affect the punctuality of operations, alleviating congestion, mitigating regulatory constraints, etc. This, with the extended integration of ATM network planning (multi-slot swapping, aircraft operator-driven prioritisation processes etc.) and cooperation on enhanced collaborative airport performance planning and monitoring, will enable passengers to have a full picture of their journey and optimise their D2D time.

The concept of airport collaborative decision making (A-CDM) has proven the benefits of sharing information and procedures between airport stakeholders and the wider ATM network. The A-CDM concept will be extended to encompass specific stakeholder information requirements relating to elements of the multimodal journey and fully included in the AOP and NOP collaborative processes.

Understanding passenger origin-destinations will ensure easy access/egress for all passengers (not only those from the nearby city) and optimal landside and airside design. Use of AI will help optimise pre-screening of passengers and departure / arrival queues /sequences in order to accommodate as much door-to-door journeys as possible. Single ticketing and remote check-in/bag-drop will enable smooth transit and easier planning of the passenger journey. Mobility as a service (MaaS) will help with this planning and provide alternative routings in case of disruption. This will require seamless integration between ATM, UAM (see section 3.4), and surface transport. The integration of vertiports into airport operations and city surface transport networks will allow the rapid transfer of some passengers' right to the heart of an airport using UAS/UAM and facilitate the introduction of point-to-point inter-urban UAS/ UAM flights. This SRIA targets demonstrating such

integration through at least one operational implementation in a European city before 2027.

Passenger experience at the airport

Smart airports, with landside and groundside fully integrated into the ATM network, will be based around connectivity and other technologies to improve operations and the user experience. The integration of airport and network planning and the timely exchange of surface network, airport and ATM network information will bring common situational awareness and improved mobility planning activities, notably arrival and departure predictability for both airports and the network. Information-sharing and collaborative decision-making will allow the inclusion of outputs from landside processes (passenger and baggage) to be used to improve the accuracy and predictability of airside operations. Business intelligence and machine learning will help airport stakeholders collaborate to align process and resource capacity with predicted demand to reduce queues. Airport design should favour optimised intra-airport flow, reduced queuing for airport services (check-in, bag scan, immigration, bag reclaim, etc.) and reduced walking distance for passengers, fast and efficient boarding and disembarkation, and should allow passengers to spend buffer time usefully, enjoyably and comfortably, for either leisure or work.

Drivers for this will include the digital evolution of integrated surface movement, multimodal airport collaborative decision-making and flow optimisation, next-generation arrival manager in a 4D context, and enhanced integration between airspace users' trajectory definitions and ATM NM processes. The target is to have two pilot implementations of fully integrated multimodal smart airports with the ATM Network before 2027.

An integrated transport network performance cockpit

The aviation network performance cockpit introduced in Section 3.3 will be further developed into an overall transport network performance cockpit to improve passenger experience and planning. This will require collaboration between different modes of transport, a detailed analysis of existing data and processes for their integration, and the specification of needs for additional data collection and analysis. Data from various sources, aligned with powerful analytics, will allow the creation of data-based services supporting journey optimisation and personalisation of offers to customers. EU General Data Protection Rules will be respected to protect personal data. For aviation, the Network Manager's data collection and processes will be enhanced to support the multi-model dimension. Enhanced transport performance indicators will be developed to support the analysis of passenger experience based on the current SES performance scheme, ICAO, EU connectivity indicators and indicators used in other modes of transport. Prospective socio-economic studies will provide insight into the challenges of the evolution of air transport within the general transport system. The target is to support the implementation of the ATM network performance cockpit by 2023 and, on this basis, develop the detailed integrated transport network performance cockpit concept and requirements by 2027.

An integrated transport network crisis management process

Recent events (e.g. terrorist attacks) demonstrated the need to coordinate – when managing a crisis - between different modes of transport and a multitude of actors, including local and national authorities' representatives to increase overall transport system resilience and provide a better service to the customers. The target is to develop, starting from the Network Manager crisis management process, the detailed requirements and concept for the integrated transport system crisis management process, before 2027.

DEPENDENCIES WITH OTHER INITIATIVES IF REQUIRED

- European Institute of Innovation and Technology Urban Mobility

  The Urban Mobility partnership will integrate user-focused mobility services and products by accelerating the development and deployment of novel and data-driven mobility services and products to provide synergies and complementarities in tackling questions related to data-sharing (ownership, privacy, security, technical solutions for data supply and consolidation, etc.).

- European Partnership for transforming Europe's rail system

  One of this partnership's aims is to integrate rail into digital multimodal mobility and logistics, starting from the achievements of Shift2Rail. As airports are multimodal nodes for aviation, cooperation on enhanced collaborative airport multimodal performance planning and monitoring could prove beneficial for both partnerships. Moreover, the enhancement of air-rail co-modality (e.g. through single-ticketing) will help overcome airport congestion and support optimisation of passenger flows in areas up to 500 km around the aviation hubs.

- European Partnership for Clean Aviation (EPCA)

  The proposed European Partnership for Clean Aviation aims to develop and demonstrate disruptive "clean sheet" aircraft concepts for the regional, short and medium range segments of the air transport system. Key enabling technologies to be investigated include (hybrid) electric architectures, ultra-advanced propulsion, system and airframe concepts, and the potential use of hydrogen based energy systems. In order to ensure that aircraft deploying these solutions are safe, reliable, affordable and globally competitive, a strong increase in the integration of digital design and operating systems and in the deployment of automation and autonomy in aircraft systems and air operations will be essential. Developing and validating digital capabilities for aircraft design and for the aircraft flight control and operation will be a key driver of the transformation and will be integral to the EPCA efforts. The insertion of these low- to net zero emissions aircraft will also depend on the implementation of the Digital European Sky with its connectivity and autonomy flagship activities. This digital transformation along with the potential for new operating concepts will be important areas for collaboration and synergies with the Integrated ATM Partnership. Joint technology roadmaps, shared and collaborative pathways and joint integrated large scale demonstration efforts are foreseen.

- Connected, Cooperative and Automated Mobility (CCAM)

  The CCAM partnership will demonstrate inclusive, user-oriented and well-integrated mobility concepts that bring a reduced carbon footprint and reliable predicted travel times, enabling congestion management using real-time information. Integrating such concepts with collaborative constraints management around airports, as ultimately targeted by the ATM Network Performance Cockpit, could potentially significantly improve the performance of the Integrated Transport System and the overall journey experience for passengers.

- There would be strong dependencies and potential synergies with any consolidated R&I actions dealing with the optimisation of (road) infrastructure development at and around airports and its integration within the regional networks, as well as the advent of performant inter-city or inter-airports road transport services. Throughout its lifetime, the partnership will monitor such developments with a view of engaging in cooperation if the opportunity arises.

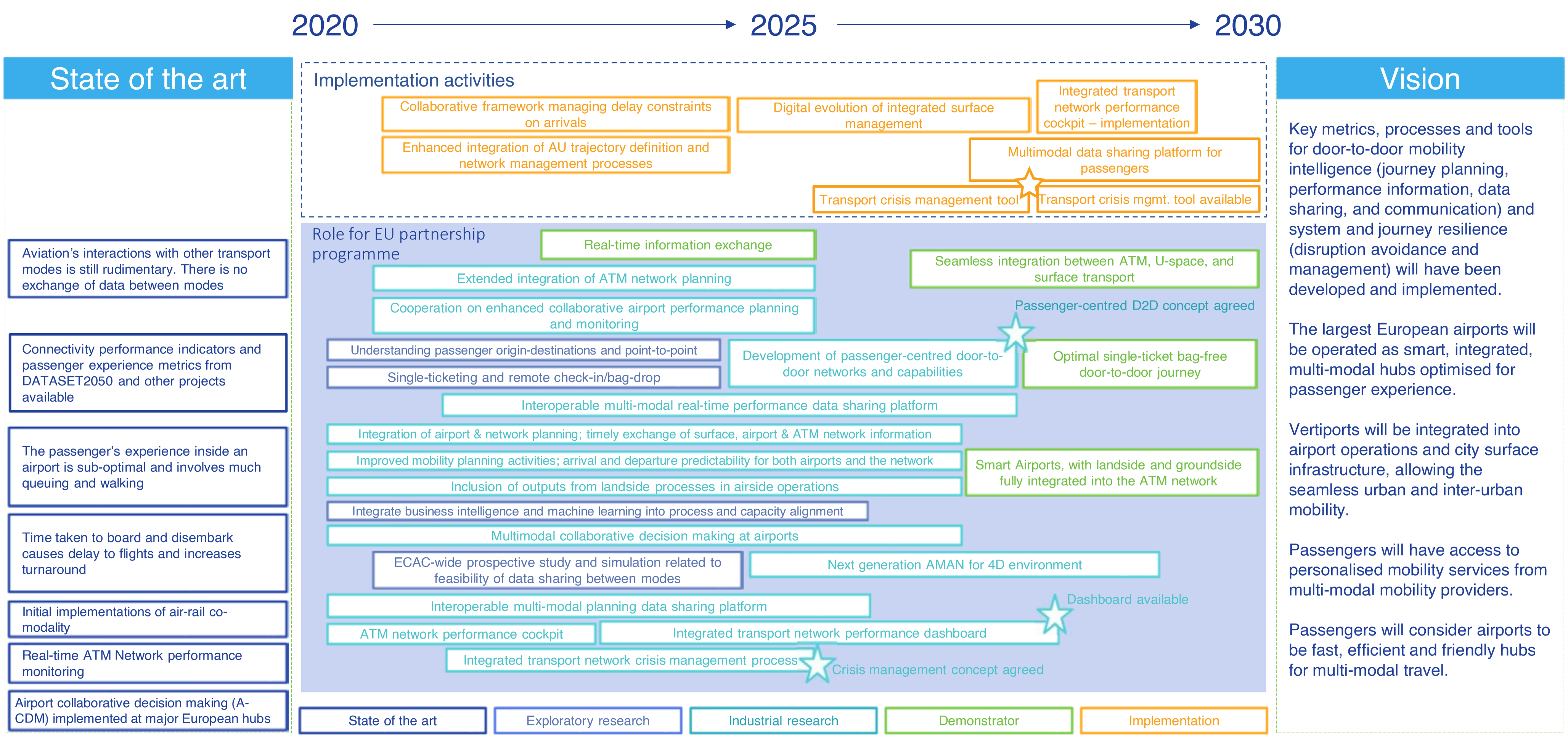
- Internal to this SRIA, this section has dependencies with sections 3.3, 3.4, 3.7, 3.8 and 4.1.

EXPECTED HIGH-LEVEL OUTCOMES AND PERFORMANCE OBJECTIVES

The qualitative assessment below is to be read as the contribution of the multimodal elements to the overall performance benefits brought by the related enablers/capabilities.

Environment (+)	Optimised operations due to improved gate-to-gate planning contribute to the optimisation of fuel-burn and therefore of CO_2 emissions per flight. Additional environmental benefits will come from alleviating congestion at and around airports by improving passenger flows (through predictability and single-ticketing), from helping access/egress to/from airports, using environmentally-friendly means, and from integrating vertiports for electric UAM vehicles.
Passenger experience (+)	Sharing data on air transport with travel service providers will help passengers plan intermodal journeys that include air segments. During the journey, complete integration of airports as multimodal nodes into the ATM network will enable full and seamless interoperability between the surface transport network, airports, AO and NM systems, contributing to increasing network resilience and the reliability and predictability of journey parameters, enhancing punctuality and passenger experience overall.
Capacity (+)	Fully integrating the most congested airports into the ATM planning process, introducing tools that allow user-driven prioritisation based on real-time multimodal passenger constraint information, monitored and shared accurately at Network level, will help reduce departure delay, while improving IFR movement numbers at these airports and ultimately IFR network throughput.
Cost efficiency (+)	The data-sharing-powered network performance cockpit will enable increased predictability of traffic flows coupled with increased network flexibility and resilience. This would in turn help reduce en-route congestion and air navigation service (ANS) costs. New data-sharing standards and systems will allow new 'as a service' businesses, creating more value for aviation, within an integrated transport-system.
Operational efficiency (+)	Improved, accurate, customer-focused planning, including user-driven prioritisation, allows operators to customise and optimise every flight, balancing their individual constraints against those of the Network, with a direct positive impact on additional gate-to-gate flight time, fuel burn per flight, and operational costs from congestion and disruption. There will be also a positive impact on resilience from data-sharing, increase knowledge and integrated network crisis management processes.
Safety (+)	Better integration of UAS, UAM and GA operations at airports and within TMAs will directly contribute to increased, seamless, and hassle-free mobility while enhancing operational safety. Similarly, punctual, predictable, integrated ground transport to/from the airport will reduce passenger stress and contribute to reducing stress-related accidents.

ROADMAP 6 – MULTIMODALITY AND PASSENGER EXPERIENCE



Source: SESAR 2020 PJ.20 (W2) project partners

3.7 AVIATION GREEN DEAL

PROBLEM STATEMENT

The objective of net-zero greenhouse gas emissions by 2050 set by the European Green Deal[3], in line with the EU's commitment to global climate action under the Paris Agreement, requires accelerating the shift to smarter and more sustainable mobility. This implies the need for aviation to intensify its efforts to reduce emissions, in line with the targets set in Flightpath 2050[4]. To this end, a set of operational measures to improve the fuel efficiency of flights will have to be put in place. At the same time, to ensure sustainable air traffic growth, it is necessary to speed up the modernisation of the air infrastructure to offer more capability and capacity, making it more resilient to future traffic demand and adaptable through more flexible air traffic management procedures and a charging scheme that does not make it interesting to fly unnecessary distance. Furthermore, reducing aircraft noise impacts and improving air quality will remain a priority around airports.

DESCRIPTION OF HIGH-LEVEL R&I NEEDS/ CHALLENGES

Optimum green trajectories

The objective is to enable aircraft to fly their optimum fuel-efficient 4D trajectory (cross-border, where applicable). ATC actions should preserve as much as possible this optimum green trajectory from any potential degradation and from the associated additional emissions. Thanks to data sharing between all the actors (e.g. airlines, airports at departure and arrival, Network Manager and often multiple national air navigation and data service providers) involved in the execution of a given flight, monitoring tools and appropriate measures have to be defined to remove or reduce any gap between the optimal 4D trajectory and the planned or in execution trajectory. In terminal areas, it will be necessary to find the best possible compromise between maintaining the optimum fuel-efficient 4D and minimising the noise impact. Optimal green trajectories should also include and anticipate the challenges and performance characteristics of new aircraft types and propulsion that the European Partnership for Clean Aviation will deliver.

New ways of flying

This includes the exploration of innovative flight operations based either on existing or future avionics that reduce the environmental impact of aviation (both emissions and noise) without compromising safety, for example more efficient ATFCM services or the application of short-term ATFCM measures (STAM) to flight paths, limiting the need to apply horizontal and vertical re-routings.

Formation Flight[1]

Using the principle of wake-energy retrieval like migrating birds, formation flight tests have demonstrated that significant fuel savings (between 5-10% per trip) could be achieved when two aircraft fly approximately 3 kilometres apart, without compromising passenger comfort and safety. R&I activities will develop the required avionics and the necessary ATM procedures to develop demonstrators and prepare for market uptake.

Advanced RNP green approaches

New procedures design will allow to define shorter horizontal path of arrivals while insuring low noise impact over populated areas. For instance by using the most advanced RNP aircraft capabilities and by sharing precise 4D trajectories, further optimisation of arrival trajectories can be achieved with shorter downwind legs, shorter final legs and optimal transition from cruise phase. The integration of each improvement into an optimal arrival trajectory will shorten flight

1 First step: Initial Operational Capability could be envisaged from around 2025: targeted over the North Atlantic with the relevant ANSPs and probably one airline flying (maybe two). On Airbus side, the first certified aircraft type would be the A350. Second step: around 2027/2028, extend to more airlines with the associated business model to organise the flights and the aircraft pairs (leader/follower) on Oceanic North Atlantic routes, extending to Pacific routes as well as low-density continental routes (Canada, Russia, etc.). Other certified aircraft types may join.

times and emissions while maintaining the noise impact at the most acceptable levels.

Environmentally optimised climb and descent operations (OCO and ODO)

While a major collaborative effort is needed for the deployment of OCO and ODO procedures in many European TMAs and airports, with most promising environmental benefits, further studies will explore the potential of additional optimisation (e.g. delaying the deceleration phase closer to the airport). The potential for improvement will depend on both the baseline standard speed management strategy of each TMA and the sequencing method used, and needs to be further assessed in terms of benefits and applicability to European TMAs.

Non-CO_2 impacts of aviation

The impact on the climate of non-CO_2 emissions (NOx, SOx, H_2O, particulate matter, etc.), such as contrails and induced cloudiness, is potentially large. In particular, the trade-off between avoiding areas where aircraft-induced clouds form and reducing CO_2 should be studied further[2].

Impact of new entrants

The introduction of new types of air vehicles[3], such as hybrid-electric/ hydrogen/electric aircraft, drones/ UAVs or super/hyper-sonic aircraft will offer new opportunities for the development of the air transport of freight and passengers, adding to the flexibility of the system, reducing door-to-door journeys and, with the use of non-fossil fuels, reducing or eliminating associated emissions. At the same time, however, they could create new annoyances and fears among the population overflown (noise; visual pollution, particularly at night; intrusion into privacy; risks to third parties, etc.) and even risk to wildlife (e.g. migrating birds, nesting areas), notably in locations where no nuisance from aviation existed before. These impacts need to be studied further, and the operations of these new entrants adjusted to minimise them.

Accelerating decarbonisation through operational and business incentivisation

Optimisation of flight operations (including taxiing at the airport) from an environmental perspective in the context of a full door-to-door green mobility.

- Emission-free taxiing traffic management: Using a turbofan engine for taxi movements results in extended use and wear of aircraft wheel brakes as well as high emissions of carbon monoxide, unburned hydrocarbons and particulate matter, impacting local air quality. The use of emission free taxiing, without comprising punctuality, could make a fuel saving of around 2%, and as such should be further studied and generalised.
- Environmental dashboard: The collaborative management of environmental impacts and the implementation of strategies to reduce them requires the development of indicators/metrics that will enable on one hand all ATM decision-makers to make informed decisions at strategic, pre-tactical or tactical level and on the other hand to communicate on ATM community efforts towards environmental sustainability.
- Environmental impact assessment toolset: There is a need to develop further the set of European environmental impact assessment tools, in order to analyse, inter alia, the integration of new entrants into the future ATM system and the overall environmental benefits and impacts they will have. Due to the complexity and diversity of environmental impacts, particular attention needs to be paid to the analysis of trade-offs, between environmental impacts, but also possibly with other performance areas.
- Environmental impact assessment methodology and new metrics: It is necessary to develop further the methodology used in SESAR 2020 not only to cover the research phase, but also the deployment and implementation phases. As part of this methodology, the use of big data analysis and machine-learning should be extended to the development of new environmental metrics that will be used to monitor environmental impacts and incentivise actors to promote compliance with environmental targets and regulations. These metrics will also be integrated into the Environmental Dashboard, and into the Environment Impact Assessments toolset.
- Climate resilience and adaptation: All future ATM solutions must demonstrate their resilience to projected future meteorological and atmospheric conditions, which could become increasingly extreme.

2 It should be noted that technological changes to improve propulsion efficiency may increase condensation trails as exhaust fumes at low temperatures may be more likely to form ice crystals.

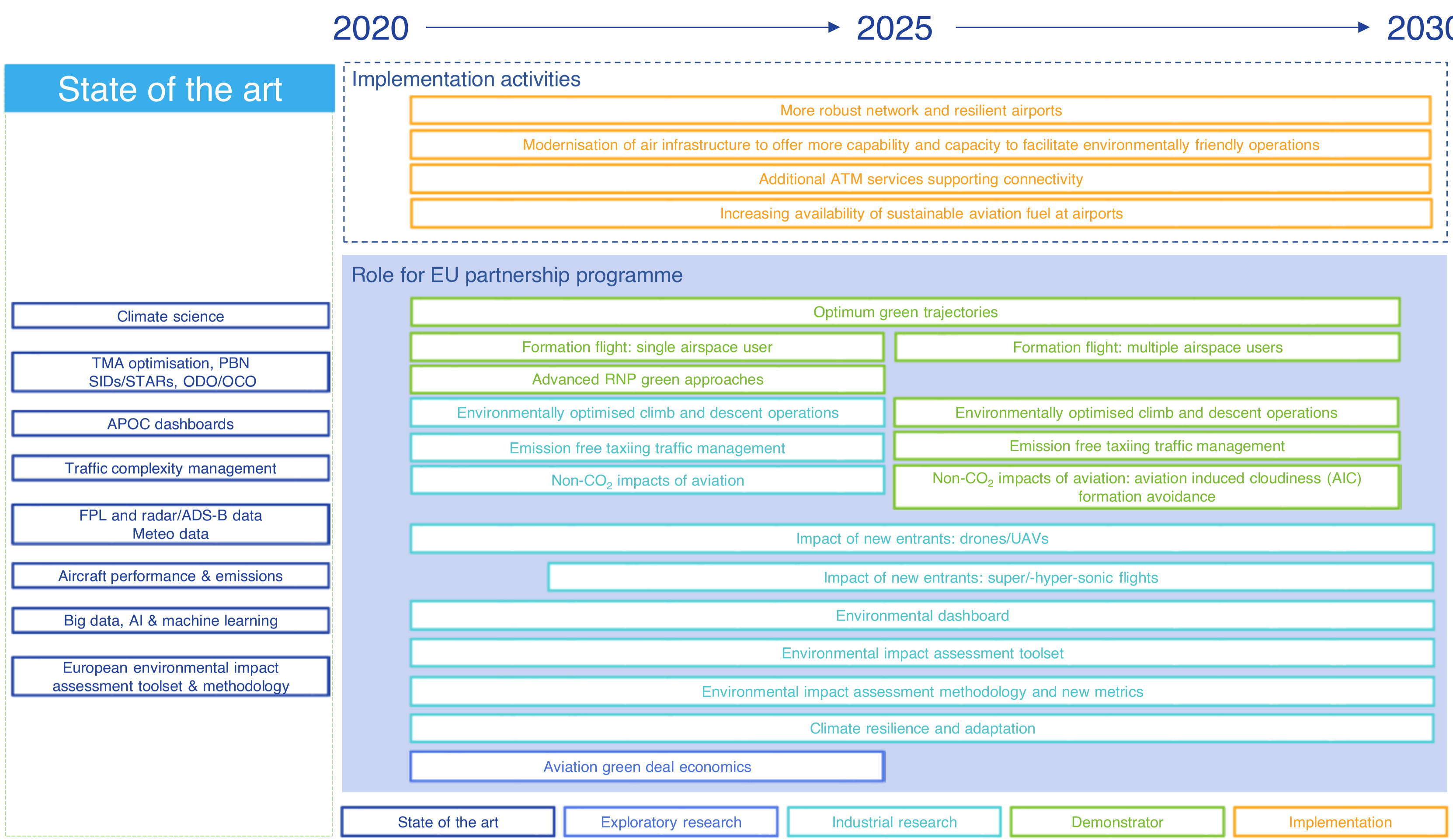
3 While the deployment of drones/UAVs and supersonic could take place in the short term, the deployment of hybrid electric, hydrogen, or fully electric aircraft is likely to take place in the medium to long term.

DEPENDENCIES WITH OTHER INITIATIVES IF REQUIRED

- Capacity-on-demand and dynamic airspace: An aviation infrastructure that is resilient to changes in traffic demand and capable of adapting, through more flexible air traffic management procedures, will result in better environmental performance.
- Multimodality and passenger experience: Today, minimising environmental impact is an essential element in guiding the choices of passengers on the most appropriate modes of transport for their journey.
- Artificial intelligence (AI) for aviation: The use of AI will enable the development of new environmental metrics and assessment models.
- European Partnership for Clean Aviation: will provide new technologies and new air vehicles that are more climate and noise efficient. Interface and synchronisation with Clean Aviation must be ensured, in particular to know more about the capabilities (altitude, speed, frequency) of future air vehicles in order to analyse their impact and integration into the future ATM system.
- Climate science: A better understanding of the climate impacts of aviation, especially non-CO_2, will enable the introduction of sound, globally harmonised policies and regulations to support climate-friendly flight operations. This will make it possible to anticipate climate impacts on aviation and take adaptation measures.
- Programme for Environment and Climate Action (LIFE): will support the development, testing or demonstration of suitable technologies or methodologies for implementation of EU environment and climate policy.
- EIT Urban Mobility-KIC: The impact of drones/UAVs on urban citizens needs to be investigated.
- EIT-Climate KIC: To ensure that good ideas are turned into positive climate action.
- European Partnership on Clean Hydrogen: Enabler for new hydrogen air vehicles.
- European Partnership for Clean Energy Transition: Enabler for the provision of renewable fuels for sustainable transport.

EXPECTED HIGH-LEVEL OUTCOMES AND PERFORMANCE OBJECTIVES

Environment (+)	Not splitting sectors further and increasing capacity will enable to optimal flight trajectories, providing important fuel efficiencies and thus CO_2 reductions. Innovative approaches such as formation flight will bring additional fuel savings.
Capacity (+)	A high level of automation will make it possible to go beyond the current limits of sector capacity due to controller workload which will allow optimal and environmentally-friendly flight trajectories.
Cost efficiency (+)	Very high benefits in productivity gain. No limitation to sector and controller workload. Saving fuel for airspace users will reduce CO_2 emissions and related costs for emission allowances.
Safety (= /+)	Safety levels are maintained or improved in case of a high level of automation. The greatest benefit would be at the highest level of automation. At intermediate level, keeping the human in the loop might be delicate and would not necessarily bring the best safety benefit. It is suggested to initially start automation at night, in oceanic or low-density airspace, in order to gain experience.



Vision

The European airspace is the most efficient and environmentally friendly sky in which to fly in

Flights are planned to maximise fuel efficiency. ATC actions preserve, as far as safety permits, this optimal planned “green trajectory” from any potential degradation.

However, in order to minimise the impact of flights on the climate, ATC manoeuvres may, from time to time, lead to a slight increase in fuel consumption. In the vicinity of airports, flight operations are designed to offer the best compromise between emissions and noise impact.

At airports operations are tailored to minimise fuel/emissions; taxiing is emissions free. All new air vehicles have been integrated seamlessly in the ATM system, with minimal additional noise or emissions pollution.

Environmental dashboards, which incorporate new metrics developed through machine learning, are providing incentives for all actors to take decisions and actions to find operational solutions that minimise environmental impacts.

Source: SESAR 2020 PJ.20 (W2) project partners

3.8 ARTIFICIAL INTELLIGENCE (AI) FOR AVIATION

PROBLEM STATEMENT

ATM decision-support techniques, mostly based on heuristics, present limitations in terms of the technology itself. Hence the performance improvements of the future cannot be achieved using legacy software system approaches.

AI is one of the main enablers to overcome the current limitations in the ATM system. A new field of opportunities arises from the general introduction of AI, enabling higher levels of automation and impacting the ATM system in different ways. The FLY AI report [10] provides a set of recommendations and real examples to help the aviation/ATM sector accelerate the uptake of AI.

AI can identify patterns in complex real-world data that human and conventional computer-assisted analyses struggle to identify, can identify events and can provide support in decision-making, even optimisation. Over recent years, developments and applications of AI have shown that it is a key ally in overcoming these present-day limitations, as in other domains.

Tomorrow's aviation infrastructure will be more data-intensive and thanks to the application of Machine Learning (ML), deep learning and big data analytics aviation practitioners will be able to design an ATM system that is smarter and safer, by constantly analysing and learning from the ATM ecosystem.

DESCRIPTION OF HIGH-LEVEL R&I NEEDS/ CHALLENGES

Trustworthy AI powered ATM environment

New and emerging AI capabilities will be required for the future ATM/U-space environment in order to provide the necessary levels of performance beyond current limits.

R&I is a key lever to deploy this technology and generate trustworthiness upon artificial intelligence in aviation, always considering a human-centric approach in line with the EASA Artificial Intelligence Roadmap [17]. Safety science will also need to evolve to cope with the safety challenges posed by the introduction of ML. Beyond the work conducted by the EUROCAE AI working group, there is the need to focus on the development of new methodologies for the validation and certification of advanced automation that ensure transparency, legal aspects, robustness and stability under all conditions and taking full consideration for a future ATM environment built on multiple AI-algorithms system of systems, with a human-centric approach.

So far, AI has been largely dependent on data, as is necessary to develop AI algorithms and to validate them. Thus, the challenge is to develop an appropriate aviation/ATM AI infrastructure that can capture the current and future information required to support AI-enabled applications with the required software developments processes, using robust architectures for ATC systems to provide ATCOs and pilots with good level of confidence of automation and decision aiding tools.

In addition, to cope with higher levels of automation, there is a need to foster access to and sharing of data while looking at data quality, data integrity, ownership, security, trust framework and data governance aspects, which will mean building an inclusive AI aviation/ATM partnership, aiming a potential leadership for AI in aviation in Europe by defining, learning and implementing together.

AI for prescriptive aviation

AI will help aviation to move forward from a reactive (to act when a problem appears) to a predictive (anticipating a problem, enabling innovative preventive actions) and even a prescriptive paradigm (adding the capability to identify a set of measures to avoid the problem). AI applications will impact all flight phases from long-term planning, through operational to post-operational analysis.

New disruptive events (e.g. the COVID-19 pandemic), have recently shown that aviation requires the implementation and adaptation of new solutions to face unexpected events of which we have no prior experience. The resilience of the ATM system shall thereby be addressed.

AI/ML have great potential for predictions/forecasts under normal circumstances, but need further evolution if they are to be used in the management of abnormal situations: a prescription-oriented approach will be needed to monitor reality and define precursors to detect deviations from what is expected. More time for reaction is the expected result. For major non-nominal situations (like volcanic ash clouds or COVID-19), new methodologies will be researched to cope with the AI gap. This includes not just the tactical phase but also the strategic phase, when the operators of the system may be interested in exploring what should be done to achieve a certain multi-objective system performance (for instance, by balancing capacity, cost efficiency and environmental impact), and a prescriptive system would be able to identify strategies.

Human – AI collaboration: digital assistants

The interaction between humans and machines powered by AI, or other sub-branches such as reinforcement learning (RL), explainable AI (XAI) or natural language processing (NLP), will positively impact the way humans and AI interact. These advances aim to increase human capabilities during complex scenarios or reduce human workload in their tasks, not to define the role of the human or to replace the human, but to support him[4].

Aviation will need to ensure a human-centric approach as described in the EASA Artificial Intelligence Roadmap [17]. Humans should understand what the systems are doing and also maintain the right level of situational awareness, i.e. to have conscience of the situation to enable human-machine to cooperate. The different levels of ATM Automation (0 to 5) described in the European ATM Master Plan[1] and Airspace Architecture Study [11], and also linked to Master Plan phases, present an evolution in the way that the human and the system interact, with different transparency and explainability needs. This SRIA aims at laying the foundations for an automation level of up to 4.

AI-based human operator support tools that ensure the safe integration of "new entrant" aircraft types into an increasingly busy, heterogeneous and complex traffic mix (i.e. UAVs, supersonic aircraft, hybrid and fully electric aircraft) should be developed. In addition, AI-powered systems are expected to be integrated into ground/cockpit systems, enhancing communication for trajectory management and much more. Digital assistants will request to be connected to the avionics world in order to ease data exchanges: in this context, cybersecurity will be a key enabler of these exchanges. Moreover, digital assistants will support pilots, thus reducing the workload (e.g. automating non-critical tasks, adapting the human-machine interface during operations). This is a first step towards introducing the artificial co-pilot necessary for future operations like SPO.

There will be a need to develop new HMI interfaces for ATCOs (e.g. augmented reality) and the capability to monitor ATCO workload in real time based on AI, as well as new skills and new training methods to support these new joint human machine systems.

AI Improved datasets for better airborne operations.

Datasets are essential to AI-based application development. R&I should be conducted to generate and in particular to enable the automation of such aviation-specific data sets from a large variety of on-board and ground communication across the network, which could then a enable broad range of AI-based applications for aviation (e.g. voice communications between ATC and pilots). New sensors will be loaded on board (drones/UAV and aircraft) such as camera, millimetre wave (MMW) radar, detect and avoid (DAA), light detection and ranging (LIDAR) in order to be able to execute new types of operations (automatic take-off or landing, etc.). These new operations will require new functions, such as intelligent augmentation tools, vision-based navigation or trajectory optimisation. This will enable the use of AI as a response to the European Green Deal [3], applying operational strategy based on environmental criteria and developing AI-based solutions to operational mitigations of aviation's environmental impact, such as near-real-time network optimisation (airspace/route availability) and use (on-the-fly flight planning), in conjunction with meteorological data nowcasting, which could be made possible with AI.

Furthermore, thanks to permanent high bandwidth connectivity, most data and meta data could be processed either on the ground or directly on-board. These functions will require a new high-performance service platform interfacing the ground (or cloud) open world platform (AOC) and on-board avionics for which AI will be required to remain cyber resilient. Aspects related to cybersecurity will need to evolve to cope with AI evolution needs.

4 See also [1] European ATM Master Plan, Chapter 4.5

DEPENDENCIES WITH OTHER INITIATIVES IF REQUIRED

The EC recommendation established the High-Level Expert Group on Artificial Intelligence (AI HLEG), which produced the FLY AI report [10]. This output, together with the EASA Artificial Intelligence Roadmap [17] and EUROCAE standardisation effort, shall be taken as inputs.

Moreover, close collaboration should be established with the AI PPP and the Digital Europe Programme to ensure that AI for aviation thread is aligned with the evolution of AI, and its partners can benefit from this AI community and their developments, notably in terms of capacity building.

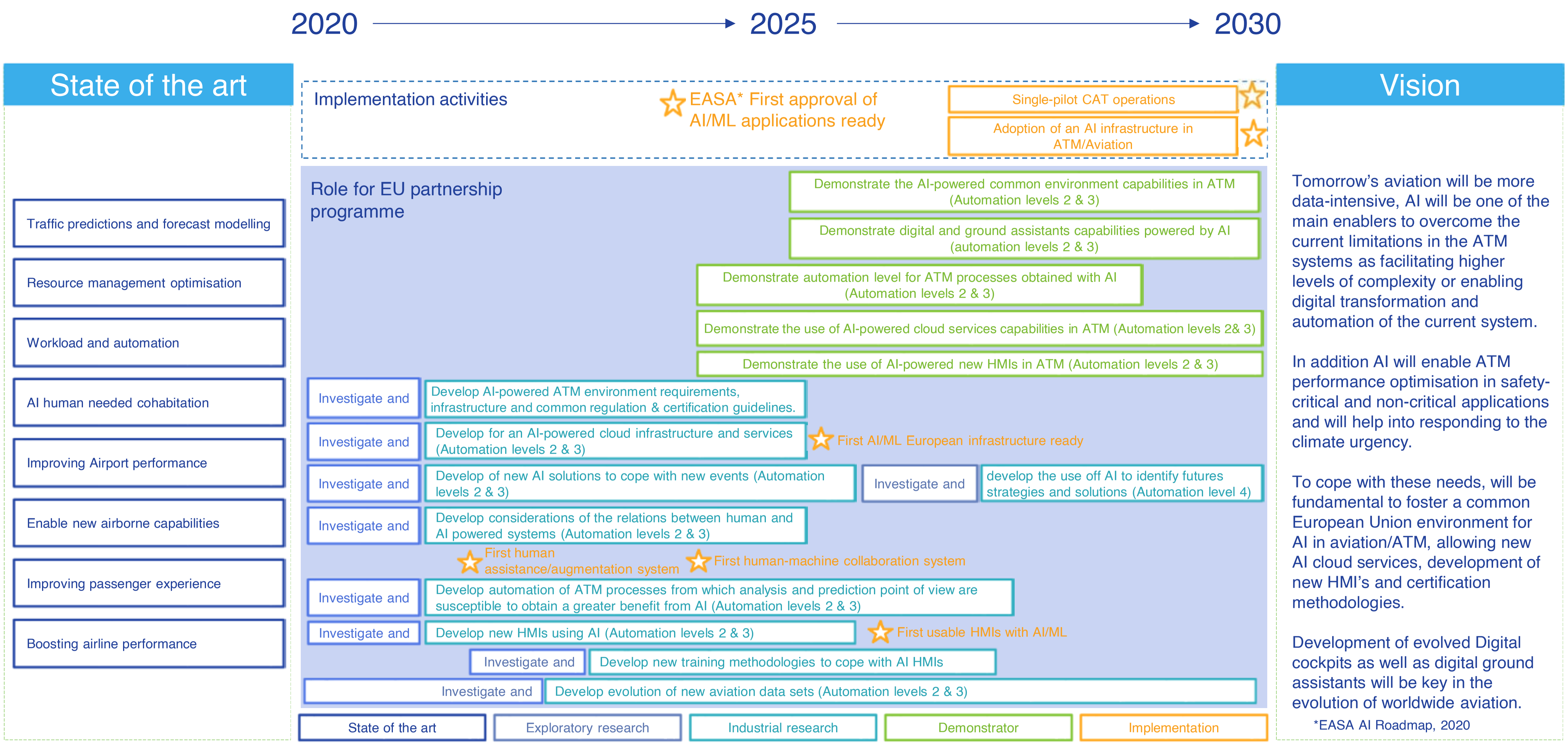
Finally, works being carried out by the Institute of human machine cognition (IHMC) will be monitored to establish a potential relationship.

EXPECTED HIGH-LEVEL OUTCOMES AND PERFORMANCE OBJECTIVES

The performance objectives are to enable ATM performance optimisation with dependency to all other R&D topics described in section 3, in particular considering a multi-objective approach:

Environment (+)	AI will enable the optimisation of aircraft trajectories, allowing a potential reduction in the aviation environmental footprint.
Capacity (+)	AI will play a fundamental role in aviation/ATM to address airspace capacity shortages, enabling dynamic configuration of the airspace and allowing dynamic spacing separation between aircrafts.
Cost efficiency (+)	AI will enrich aviation datasets with new types of datasets unlocking air/ground AI-based applications, fostering data-sharing and building up an inclusive AI aviation/ATM partnership. This will support decision-makers, pilots, air traffic controllers and other stakeholders, bringing benefits in cost efficiency by increasing ATCO productivity (reducing workload and increasing complexity capabilities).
Operational efficiency (+)	Increasing predictability will be a key role for AI, by enabling traffic predictions and forecasts that will boost punctuality.
Safety (=)	Safety science will also need to evolve to cope with the safety challenges posed by the introduction of machine learning. Actual safety levels will be at least maintained using this technology.
Security (=)	AI will offer the possibility to stay cyber resilient to new technologies and threats, the objective is to maintain a high level of security.

ROADMAP 8 – ARTIFICIAL INTELLIGENCE (AI) FOR AVIATION



Source: SESAR 2020 PJ.20 (W2) project partners

3.9 CIVIL/MILITARY INTEROPERABILITY AND COORDINATION

PROBLEM STATEMENT

The digital transformation of the European ATM network will have an impact on both civil and military aviation and ATM operations. Care must be taken to ensure a sufficient level of civil/military interoperability and coordination, especially concerning trajectory and airspace information exchange, as well as the use of interoperable CNS technologies. Therefore, a joint and cooperative civil-military approach to ATM modernisation would be the best choice to achieve the appropriate level of interoperability, also maximising synergies between civil and military research and development activities.

DESCRIPTION OF HIGH-LEVEL R&I NEEDS/ CHALLENGES

To achieve the SES objectives while at the same time enhancing military mission efectiveness, a joint research and development programme should focus on the following key priorities:

Access to airspace

For reasons of national and international security and defence, military manned and unmanned assets will require access to airspace where and when needed. Size and location of airspace for military purposes will depend on respective mission profiles. In order to make optimal use of airspace for civil and military aviation, future system options for civil-military collaborative decision-making processes supported by common procedures, data formats and the underlying information exchange services should be examined. These future systems and procedures should be flexible enough to adapt to different operational scenarios and needs, and ensure optimal separation management (e.g. DMA 3) taking into account different and coexistent CNS air and ground capabilities. It is a precondition to accommodate civil and military operations in the same airspace.

Military surveillance capabilities

To ensure situational security awareness and to improve the maintenance of their Recognised Air Picture (RAP), military authorities must monitor the air traffic inside their national airspace. The increased availability of data (such as aeronautical, meteorological, environmental and flight data) in a digital format can improve military surveillance capabilities. As also identified in the Action Area 4.9 of ACARE SRIA 2017 update Vol.1 [15], military authorities must have full access to all available information without additional cost. Increased civil-military data-sharing requires solutions ensuring the appropriate levels of quality of service and security for military systems.

Connectivity and access to CNS infrastructure

Future technical solutions making use of emerging SATCOM and terrestrial datalink technologies and multilink, as well as advanced navigation and surveillance should enable a joint civil and military utilisation, reducing technical constraints and costs while maintaining appropriate levels of safety, security and environmental sustainability. The connectivity and access to CNS infrastructure also requires solutions ensuring security and appropriate levels of quality of service. At same time, the integration of CNS and spectrum consistency in terms of robustness, spectrum use and interoperability is essential to define the future integrated CNS architecture and spectrum strategy. A service-driven approach, accommodating civil and military alike is needed to describe how the CNS services are delivered for navigation, communication, surveillance and traffic or flight information, including cross-domain services (e.g. contingencies). Further military and civil interoperability is expected in terms of the common use of CNS, rationalising civil infrastructure and costs, taking into account the capacity of military legacy systems to evolve. Research initiatives are needed to enable the use of multi-mode avionics relying on software-defined radios and reliance on enhanced visual systems and airborne surveillance to mitigate airborne collision functions. The success of military missions depends on adequate access to RF spectrum re-

sources, in particular to ensure the mobility and interoperability of forces. The digitalisation of ATC systems enables virtualisation approaches where remote operations become an important contributor for resource pooling and sharing and rationalisation. Virtual control centres allow for a more efficient and flexible use of resources, with civil/military synergies.

Cybersecurity

In a highly information-oriented operational system, data becomes a core asset to be protected. Civil-military data-sharing requires solutions ensuring the appropriate levels of quality of service and security for military systems. A necessary precondition to support the digitalisation of processes is a sufficient level of cybersecurity and data-protection, which should be considered holistically in an end-to-end information management process. Further aspects to consider are personnel education, training and capacity building, technical infrastructure and increased cooperation and information-sharing among civil and military authorities.

Performance orientation

Environmental sustainability, cost efficiency or delays imposed by inefficient use of available capacity represent a concern against which all aviation stakeholders have to assume responsibility. The complex interdependencies between civil and military stakeholders need to be examined to enable appropriate performance measurements in a spirit of balanced consideration between commercial needs and security and defence requirements.

DEPENDENCIES WITH OTHER INITIATIVES IF REQUIRED

Civil/Military ATM coordination is a transversal function, therefore there are links with many other ATM domains and functions such as cybersecurity. Synergies with new EU defence initiatives such as European Defence Fund and military mobility must be encouraged.

EXPECTED HIGH-LEVEL OUTCOMES AND PERFORMANCE OBJECTIVES

The expected high level outcomes could be classified as:

- Direct contributions to military mission effectiveness through improved CDM in the mission planning phase; increased adherence to planned trajectories, accommodation of unpredictable and complex mission profiles, enriched surveillance and threat detection at a reasonable cost.
- Indirect contributions to the European network's performance as regards safety, predictability, capacity, flight efficiency and CO_2 emissions reduction for all operational stakeholders, especially resulting from a common civil/military approach in defining the European ATM Architecture (EATMA) evolution that respects the national and collective defence requirements.

The related military ambition is to execute missions as required. Achieving higher congruence between mission-planning and execution leads to greater mission-effectiveness and the improved predictability of 4D mission trajectories. The qualitative assessment below is to be read as the contribution of civil/military interoperability and coordination to the overall network performance arising from the deployment of specific enablers and related capabilities.

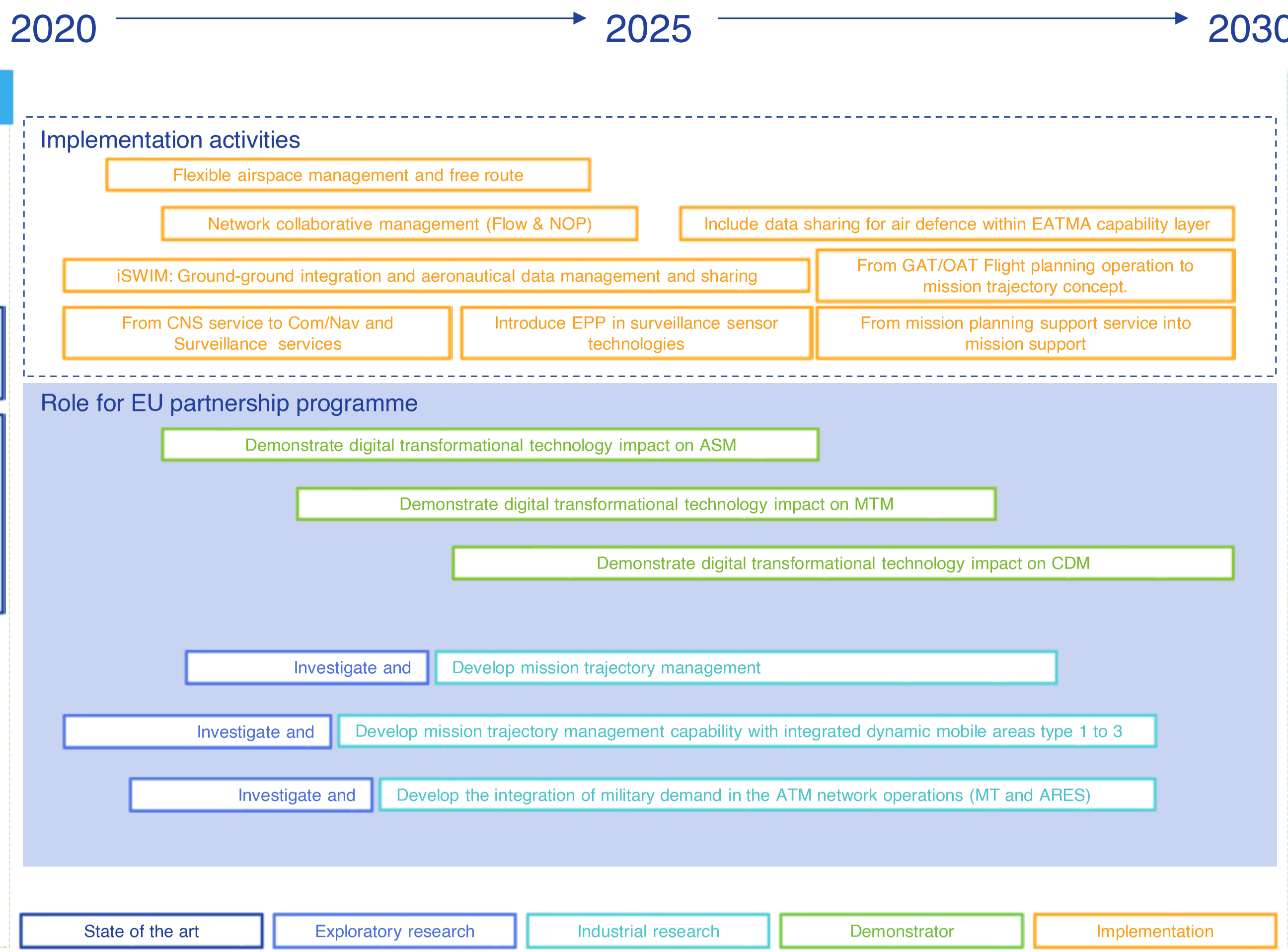
Environment (+)	The additional predictability resulting from the integration of military flight data into the network, will lead to more efficient use of available airspace capacity by civil traffic, which will lead to greater fuel efficiency.
Capacity (+)	The additional predictability resulting from the integration of military flight data into the network, will lead to more efficient use of available airspace capacity by civil traffic which will lead to fewer delays.
Operational efficiency (+)	Greater mission predictability will be of benefit to the operational efficiency of civil traffic in the European Network.
Security (+)	The confidentiality, integrity and availability of information and data is crucial in ensuring safe and secure military operations. The development of a secure virtual infrastructure would address the fragmentation issue, while digital technologies are viable options for enhancing the resilience of infrastructure to cyberattacks.
Civil-Military Coordination (+)	The coordination of sharable data relating to the mission trajectory with the Network Manager will ensure the optimal and timely integration of military flight data into the network, thus allowing solid and reliable traffic predictions.

ROADMAP 9 – CIVIL/MILITARY INTEROPERABILITY AND COORDINATION

State of the art

Mission trajectory management (MTM) ConOps and guidelines are being developed

The local and sub-regional airspace management support system, LARA, supports in real time the automatic exchange of airspace information between military and civil service providers



Vision

Digitalisation for ASM and MTM allows better integration of military requirements within ATM network operations. This enables the optimisation of trade-off between operational **efficiency**, **flexibility** and **predictability** of operations.

Cloud, big data technologies and machine learning algorithms will allow exploiting **conventional ATM data**, and **non-conventional data** (video and voice records, passengers' information, etc.) to make accurate predictions of the impact of different **airspace** and **mission design** and management options, thus supporting the relevant **decision making processes**. This will allows decoupling the provision of technical **capabilities** from the technical **infrastructure** necessary to **provide services.**

Challenges to be tackled are **resilience to cyber attack**, **more standards**, **high quality data** and an optimal **level of trust** between users and technology.

Digital technologies are essential for the transformation of military capabilities, in support of the ATM future Interconnected network.

Source: SESAR 2020 PJ.20 (W2) project partners

4 Overall output performance and economic impact

Aviation enabled by ATM is a major contributor to Europe's economy, in terms of both business and leisure travel and cargo operations. With operations now extending to U-space, aviation looks set to bring additional economic and societal benefits. The sector also creates intangible benefits, making possible cultural interchanges between people and communities all across Europe and the world.

The performance objectives of this Digital European Sky SRIA are aligned with the performance ambitions of the European ATM Master Plan 2020 edition [1]. This SRIA is a pre-requisite for these ambitions to be realised as it enables the timely and complete optimisation of the aviation infrastructure. The European ATM Master Plan performance ambitions have been derived by envisioning an optimised ATM system, which will eliminate the inefficiencies of the current system.

This SRIA brings together a unique set of partners from all areas of traditional ATM and the U-space, working together to deliver outputs and performance improvements in an integrated manner.

The future partnership will deliver the expected performance benefits in the key performance areas through the R&I and Digital Sky demonstrator developments identified in Chapter 3. Where needed, this SRIA enhances the Master Plan performance framework with additional performance indicators. The first part of this chapter looks at the consolidated key performance areas, while the second part derives the economic benefits.

4.1 Performance

This chapter presents the consolidated performance impact of the SRIA with references to the respective sections in Chapter 3.

Environment

At the heart of this SRIA is the focus on the European Green Deal and the considerable reduction of the impact that aviation will have on the environment. The European ATM Master Plan 2020 edition sets the performance ambition to a reduction of gate-to-gate CO_2 emissions by 5-10%. For aviation, this also means savings on CO_2 emission allowances to a value in excess of EUR 2 billion. As laid out in Section 3.7, overall air vehicles must have net-zero greenhouse gas emissions by 2050. This will be supported by emission-free taxiing and solutions to optimise airport and terminal airspace operations, such as exceptional holdings and more continuous climb and descent operations (CCO/CDO) (§3.1, §3.2, §3.3), while curved, steep and/or segmented approaches and noise-preferential routes are being considered for deployment to address noise reduction (§3.3). Urban air mobility will depend on electric or hydrogen-powered vehicles that will be emission free (§3.4), with R&I ensuring that noise levels are minimised for the general public.

The environmental performance of aviation will be achieved through effective coordination and cooperation with the measures listed in the Clean Aviation SRIA.

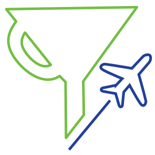
Passenger experience

ATM's contribution to passenger experience and to the implementation of efficient multimodality (§3.6), including urban air mobility (§3.4), will be a major factor in society's attitude to the performance of aviation in the future. The passenger experience will be optimised by focusing on departure and arrival punctuality on the aviation legs of the multimodal journey, reducing time spent at airports. Optimisation will also be achieved through the effective sharing of multimodal connection data with other modes of transport, enabling an integrated approach to reducing door-to-door travel time.

Expressed in monetary terms, the passenger time savings are valued in excess of EUR 200 billion.

The passenger experience will be positively impacted by the implementation of the ATM network performance cockpit, supporting an integrated transport network performance cockpit. This will be achieved in cooperation and coordination with other SRIAs on mobility and multimodality.

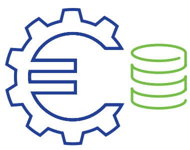
Efficient multimodal disruption management will also minimise the impact on passengers. Furthermore, a connectivity indicator will show progress towards enabling better connectivity for European citizens. The benefit to the consumer of increased availability of flights and connections represents around EUR 130 billion for the timeframe considered. Overall, passengers in the network gain EUR 330 billion for the period 2021-2027.



Capacity

Airspace and airport capacity has been an issue in the recent past, as substantiated by STATFOR's Challenges of Growth report[5], which predicts some 1.5 million unaccommodated flights by 2040 in a "do-nothing" scenario. While the COVID-19 crisis has hit aviation extremely hard and created an unprecedented trough in demand, it is expected that traffic will by 2024 return to 2019 levels and grow from there as previously forecast. The recovery pattern has been derived from previous crises scenarios. The performance ambition for capacity is to accommodate all traffic forecasts in a crisis-adjusted "regulation and growth" scenario. This includes the additional 'recovered' unaccommodated demand, which can be enabled through capacity improvements at the most congested airports. Contributions will come from further automation (§3.1) and from applying AI-supported optimisation (§3.8). Applying better automation, virtualisation and more dynamic airspace configurations will equally result in improved scalability of the system (§3.3, §3.5), providing the right level of resources at the right time and at the right place throughout the network thus minimising related delays. Eventually this scalability will lead to a much more resilient ATM system (§3.3) able to cope also with crisis situations, such as the current COVID-19 crisis in an even more responsive manner.

In addition to the scope of traditional air traffic, the SRIA will ensure that the capacity needs for U-space are addressed (§3.4). An integrated ATM approach will deal with a more heterogeneous fleet of aerial vehicles and ensure that capacity levels are maintained in this changing setting.



Cost efficiency

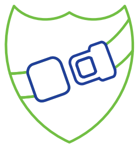
Improved cost efficiency has already been reflected in the high-level goals of 2005, with a target of reducing ATM service unit costs by 50% or more. The levels of automation and scalability reflected in this SRIA will allow for optimal use to be made of technology to support all ATM tasks. Through automation and optimised machine support (§3.1, §3.8), cost efficiency will further increase contributing to the performance ambition of reducing the gate-to-gate direct ANS cost per flight by 30-40%[6]. Moreover, the optimal allocation of resources to where they will be needed (§3.3, §3.5) and the design of U-space aviation from the outset (§3.4) will allow service delivery costs to be controlled. The expected benefits from improving cost efficiency within the 2021-2040 timeframe are monetised at an approximate value of EUR 39 billion.

Operational efficiency

The improvements in operational efficiency will lead to the minimisation of inefficiencies in system performance in terms of additional flight time per flight and improved predictability. Enhanced data sharing between all stakeholders and automation in data processing will allow the airspace users to fly their optimal 4D business/mission trajectory (§3.2, §3.3, §3.9). The influence of such things as weather will be minimised through better anticipation and more efficient coordination, reducing tactical interventions (§3.1). The improvements will lead to higher punctuality and on-time performance, taking some volatility and buffer times for operations out of the system. Consequently, the resources saved could be re-directed to the improvement of aviation connectivity.

5 In the 'Regulation and Growth' scenario envisaged by STATFOR. See Eurocontrol, 'Flight forecast to 2040 — challenges of growth', 2018 [22] (https://www.eurocontrol.int/publications/flight-forecast-2040-challenges-growth-annex-1).

6 European ATM Master Plan Performance Ambition, baseline value in 2012: EUR 960 direct ANS cost per flight gate-to-gate.



Safety

Safety remains the most important key performance area for aviation. All R&I and deployment will perform safety cases to follow the target of at least maintaining the current level of safety or improving it further. Furthermore, the elaboration of safety nets (§3.1) is targeting the avoidance of safety incidents. Automation and increased data sharing enables advanced collision avoidance and separation management (§3.2). It will also let humans focus more on safety oversight and contribute to a better anticipation of problems (§3.1, §3.2). The increased heterogeneity of aerial vehicles, including drones (§3.4), with very different flight performance, will be managed in an integrated ATM approach to ensure that there is no detrimental impact on safety. Moreover, the implementation of automation and AI will be certified to maintain, or even improve, safety levels in a growing air traffic scenario (§3.8).

Security

The goal for security is to have no significant traffic disruption due to cybersecurity vulnerabilities and ATM-related security incidents. The assessment of future R&I will systematically include a (cyber-) security evaluation of the concept and its implementation. Specifically, further automation and the implementation of machine learning and artificial intelligence must not create any (cyber-) security vulnerability. A secure virtual infrastructure will address fragmentation issues, and digital technologies provide options for bringing additional resilience to ATM systems (§3.5, §3.9) so that malicious attacks can be dealt with, causing only minimal impact. Specifically, AI will provide the possibility to stay cyber-resilient to new technologies and threats (§3.8).

Civil-military coordination

The airspace of today and the future is a resource shared between civil and the military air traffic. Optimising civil-controlled air traffic, while taking into account future military needs for training and missions, will be enabled by efficient civil-military coordination (§3.9). Automation, real-time sharing of CNS information and the air picture with the military and better network-level planning (§3.3) will minimise constraints on both sides. Society expects a fully functional, well trained military air service which has a minimal impact on civil needs. In addition, synergies for optimal sharing of physical and virtual resources and services will provide further benefits.

Digitalisation is seen as an enabler for achieving the goals of this SRIA. An initial version of an ATM Digital Index has been developed, as reflected in the European ATM Master Plan (Annex D). This will be elaborated on further to reflect the progress made as regards automation of ATM. It is linked to automation in all areas of Chapter 3 and in the digitalisation and virtualisation of services.

4.2 Economic impact

This chapter provides an assessment of the economic impact of the SRIA. The analysis focuses on the time period reflected in the holistic business view of the European ATM Master Plan. Whereas the present SRIA extends to 2027, the vast majority of benefits of a Digital European Sky materialises afterwards, as SESAR Solutions are gradually rolled out and implemented.

4.2.1 What are the positive impacts for European citizens and the economy?

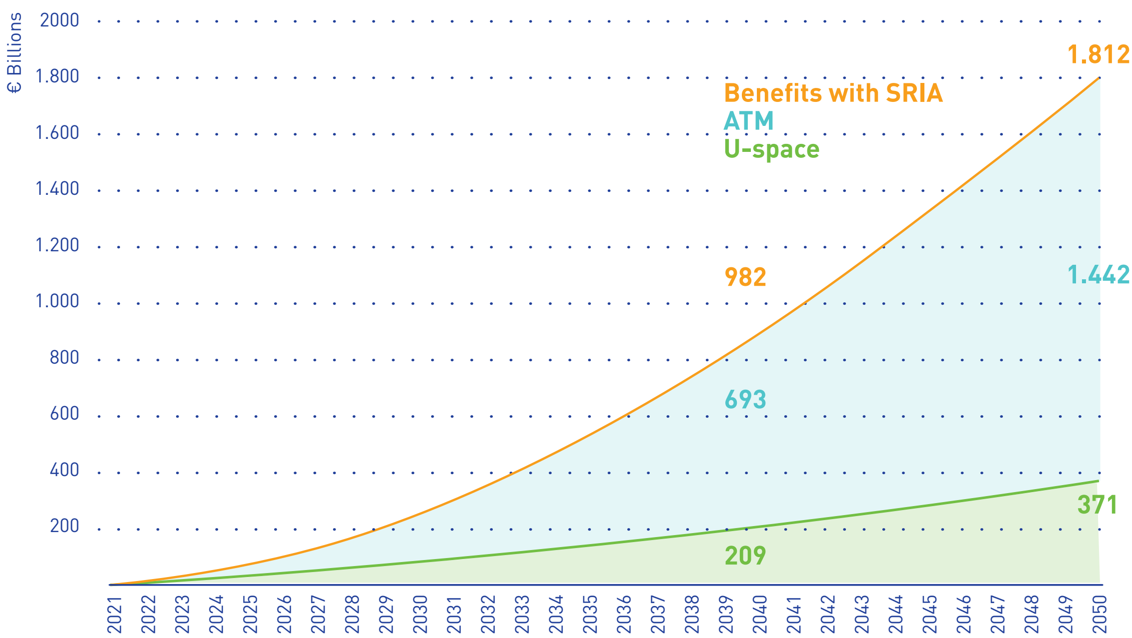
In alignment with the European ATM Master Plan [1] and its companion document [2], three types of impact have been quantified for the SESAR programme. The values are calculated by combining ATM and U-space values to show the total expected value.

- Direct impact on the aviation value chain: This includes the total gross domestic product (GDP) created by SESAR along the direct ATM value chain.
- Indirect impact on suppliers of the aviation value chain: This accounts for the increased economic activity of suppliers of the direct ATM value chain considered above.
- Quantified benefits on passengers and other impacts on society: This is the monetisation of the impact on passengers and society driven by SESAR. These are typically the value of the additional flights enabled and time savings because of minimised delays and shorter flights. Another relevant area here is the environmental benefit of SESAR in terms of climate change with lower air pollution by virtue of the improved efficiency of the system.

4.2.1.1 What benefits can this SRIA bring about?

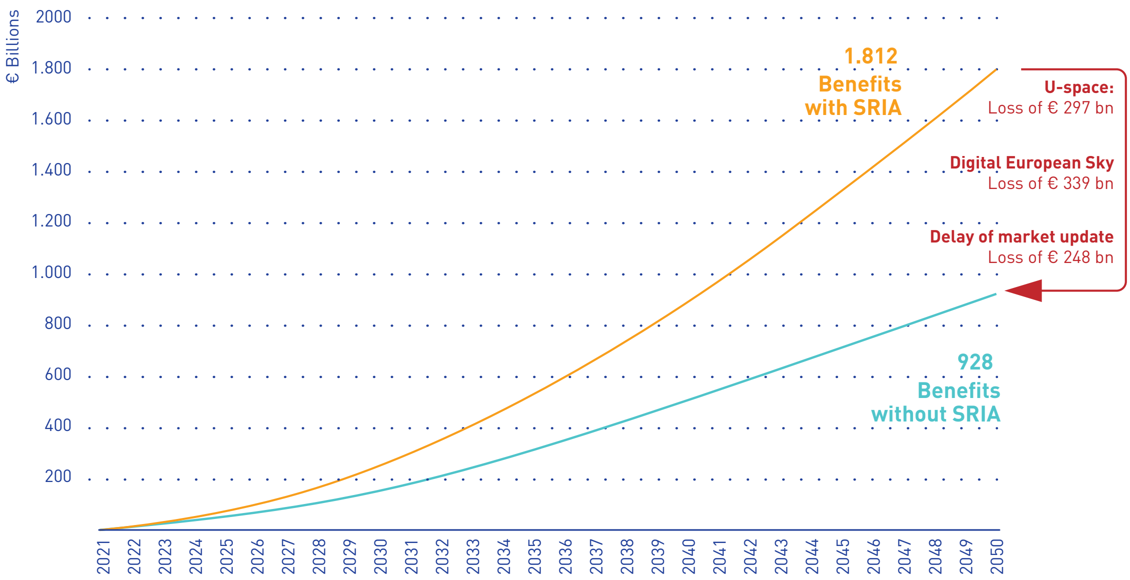
The proposed partnership is key to the successful implementation of the SESAR vision in the long term. Particularly for the SRIA time horizon, we consider the Digital European Sky is instrumental for three economic objectives that have been quantified:

Figure 13 – BENEFITS FOR 2021-2050 – CUMULATIVE VALUES



Source: SESAR 2020 PJ.20 (W2) project partners, making use of data from Master Plan 2020 edition

Figure 14 – **VALUE AT RISK WITHOUT SRIA. 2021-2050 – CUMULATIVE VALUES**



Source: SESAR 2020 PJ.20 (W2) project partners, making use of data from Master Plan 2020 edition

- Ensuring the full market potential of the U-space is achieved within the necessary timeline and in a truly integrated ATM environment.
- Delivery by 2028 of the Solutions identified in the European ATM Master Plan for phase D at TRL6.
- Increasing the market uptake for a critical mass of early mover infrastructure modernisation priorities and so ensuring the achievement of the Master Plan Performance Ambition by 2035.

The proposed SRIA is linked to unlocking the full benefits associated with achieving the SESAR vision. This is estimated at almost EUR 80 billion yearly benefits in 2040 and slightly above EUR 100 billion in 2050. When the benefits are cumulated over the 2021 to 2050 period, they are reaching benefits in excess of EUR 1800 billion. Figure 13 below shows how the benefits break down in terms of ATM and U-space.

4.2.1.2 What is the economic impact if the SRIA is not achieved?

We have estimated the economic value at risk if the SRIA content would not be materialised. In accordance with the High-Level Partnership Proposal, we have modelled a scenario where the current needs for a strengthened partnership are not met. We envisage a situation where market impact only improves marginally compared to current levels, without proper integration of U-space and without the much-needed shorter innovation cycles. Put simply, we have considered a situation "without the SRIA".

Figure 14 shows a potential economic loss of EUR 884 billion if the SRIA would not be materialised.

- **Ensuring the full market potential of U-space**: The SESAR Solutions addressing the integration of new entrants into ATM airspace require the research and innovation and implementation enabled by this SRIA. The current system and technologies are not designed to accommodate the new entrants to their full potential. Not being able to address these needs would be translated into an economic loss of almost EUR 300 billion.
- **Delivery of the Digital Sky Solutions at TRL 6 by 2028 with the phase D of the vision:** The need to maximise the exploitation of digital possibilities enabled by the Digital European Sky becomes evident when we study their

impact in our economic calculations. Failing to deliver the Digital European Sky Solutions would result in giving away around EUR 340 billion, the biggest contributor in economic value to the SRIA.

- **Acceleration of market uptake.** The SRIA is designed to facilitate market uptake for early movers addressing the priorities to deliver the ATM Master Plan performance ambition by 2035 with the phase C of the vision. Without the proposed partnership, only partially fulfilling the ambition comes at the expense of reducing the benefits to the order of EUR 250 billion.

4.2.1.3 COVID-19 crisis does not significantly change the need for and the benefits from Digital European Sky SRIA

Aviation is a resilient industry which has been hit by a number of shocks in the past. Whereas COVID-19 is currently creating unprecedented low traffic levels, in the medium to long term, there is very little doubt that aviation will return to growth. Moreover, the COVID-19 crisis does not change the need for the European ATM system to become more automated, more scalable and more resilient in its support of European aviation while reducing the environmental impact and improving cost efficiency.

Using economic modelling shows that for all cases there is a strong point supporting the described SRIA investment, which will bring back many times more benefits even in pessimistic scenarios.

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6 Glossary

Abbreviation	
AAS	Airspace architecture study
ACARE	Aeronautics research in Europe
ACAS X	Airborne collision avoidance system X
A-CDM	Airport collaborative decision making
ADS	Automatic dependent surveillance
ADS-B	Automatic dependent surveillance-broadcast
ADSP	ATM data service provider
AeroMACS	Aeronautical mobile airport communications system
AFR	Autonomous flight rules
AI	Artificial intelligence
AI HLEG	High-level expert group on artificial intelligence
AIM	Aeronautical information management
AIS	Aeronautical information services
ANS	Air navigation service
ANSP	Air navigation service provider
AO	Airport operations
AOC	Airline operation centre
AOP	Airport operations plan
APT	Airport(s)
APW	Area proximity warning
ARES	Airspace reservation
ASM	Airspace management
ATC	Air traffic control
ATCO	Air traffic control officer
ATFCM	Air traffic flow and capacity management
ATFM	Air traffic flow management
ATM	Air traffic management
ATSEP	Air traffic safety electronics personnel
ATSU	Air traffic service unit
AU	Airspace user
BI	Business intelligence
BUBBLES	Basic building blocks for U-space separation
CAPEX	Capital expenditure
CCAM	Connected, cooperative and automated mobility
CCO	Continuous climb operations
CDM	Collaborative decision making
CDO	Continuous descent operations

Abbreviation	
CNS	Communication, navigation and surveillance
CONOPS	Concept of operations
COP	Conference of the Parties (United Nations Framework Convention on Climate Change)
CORAC	Conseil pour la recherche aéronautique civile
CPDLC	Controller-pilot datalink communications
D2D	Door to door
DAA	Detect and avoid
DAC	Dynamic airspace configuration
DACUS	Demand and capacity optimisation in U-space
DCB	Demand capacity balancing
DMA	Dynamic mobile area
EASA	European Union Aviation Safety Agency
eFPL	Extended flight plan
EIT	European institute of innovation and technology
EOC	Essential operational change
EPCA	European Partnership for Clean Aviation
EPP	Extended projected profile
ESO	European standardisation organisation
ETS	EU Emissions Trading System
EU	European Union
EUROCAE	European organisation for civil aviation equipment
eVTOL	Electric powered vertical take-off and landing
FCI	Future communication infrastructure
FF-ICE	Flight and flow information for a collaborative environment
FIR	Flight information region
FO	Flight object
FOC	Flight operations centre
FOC	Full operational capability
FPL	Flight plan
FUA	Flexible use of airspace
G/G	Ground/ground
GA	General aviation
GANP	Global air navigation plan
GAT	General air traffic
GDP	Gross domestic product
GNSS	Global navigation satellite system
HALE	High altitude long endurance
HAO	Higher airspace operations

Abbreviation	
HLO	High-level operations
HLPP	High-level partnership proposal
HMI	Human-machine interface
IaaS	Infrastructure as a service
ICAO	International civil aviation organisation
ICT	Information and communications technologies
IFR	Instrument flight rules
INAP	Integrated network management and extended ATC planning
IOP	Interoperability
IoT	Internet of things
KIC	Knowledge and innovation communities
KPA	Key performance area
LAQ	Local air quality
LDAC	L-band digital aeronautical communication
LiDAR	Light detection and ranging
MaaS	Mobility as a service
MET	Meteorology/Meteorological information
ML	Machine learning
ML	Military
MMW	Millimetre-wave
MSAW	Minimum safe altitude warning
MTCD	Medium-term conflict detection
MTM	Military trajectory management
NASA	National Aeronautics and Space Administration (US)
NLP	Natural language processing
NM	Network Manager
NOI	Noise
NOP	Network operations plan
NOx	Nitrogen oxides
OEM	Original equipment manufacturer
OPEX	Operational expenditure
PaaS	Platform as a service
PinS	Point-in-space
R&D	Research and development
R&I	Research and innovation
RC	Rotorcraft
RF	Radius to a fix
RL	Reinforcement learning

Abbreviation	
RNP	Required navigation performance
RPAS	Remotely piloted aircraft system
SaaS	Software as a service
SAF	Sustainable aviation fuel
SATCOM	Satellite communications
SBAS	Satellite-based augmentation system
SES	Single European Sky
SESAR	Single European Sky ATM Research
SID	Standard instrument departure
SOA	Service-oriented architecture
SOx	Sulphur oxides
SPO	Single pilot operations
SRIA	Strategic research and innovation agenda
STAM	Short Term ATFCM Measures
STAR	Standard terminal instrument arrival route
STCA	Short-term conflict alert
SWIM	System-wide information management
TBO	Trajectory-based operation
TBS	Time-based separation
TMA	Terminal manoeuvring area
TMV	Traffic monitoring values
TRL	Technology readiness level
UAM	Urban air mobility
UAS	Unmanned aircraft system
UAV	Unmanned aerial vehicle
UDPP	User-driven prioritisation process
UTM	UAS traffic management
VFR	Visual flight rules
VHF	Very high frequency
VLD	Very large-scale demonstrations
VLL	Very low level
WOC	Wing operations centre
WX	Weather
XAI	Explainable AI

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