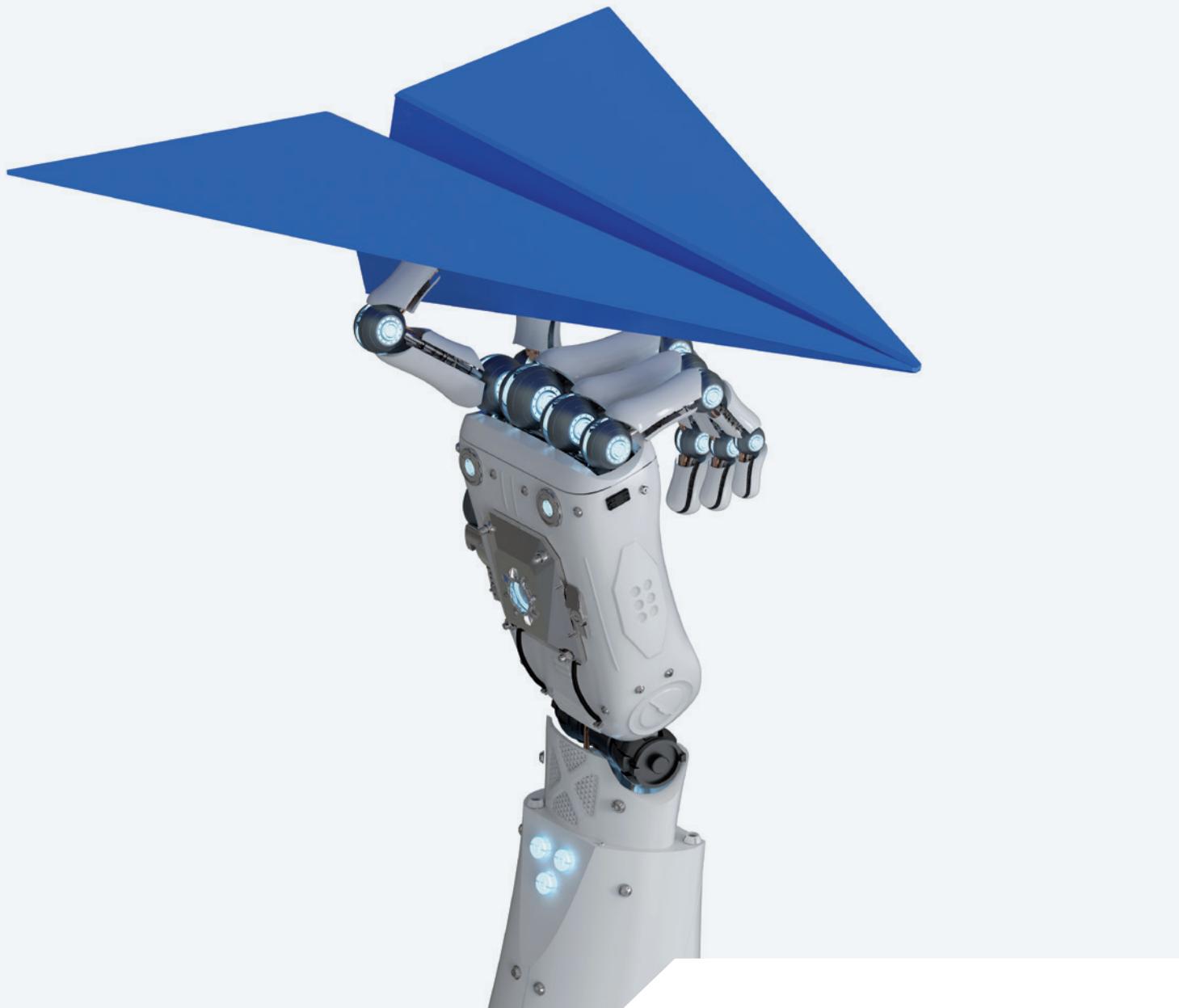


EUROPEAN AVIATION ARTIFICIAL
INTELLIGENCE HIGH LEVEL GROUP

The FLY AI Report

Demystifying and Accelerating AI in Aviation/ATM

5th March 2020



AIRBUS



Heathrow

Honeywell



IFATCA



WITH INPUTS FROM EDA MILITARY EXPERTS AND NATO ATTENDING IN AN OBSERVING CAPACITY



CONTENTS

FOREWORD	3
WELCOME MESSAGES	4
Adina Vălean, European Commissioner for Transport	4
Eamonn Brennan, Director General EUROCONTROL	5
EXECUTIVE SUMMARY	6
1. ARTIFICIAL INTELLIGENCE (AI) – SETTING THE SCENE	8
1.1. AI and Machine Learning Definitions	8
1.2. AI in Europe	10
1.3. AI in support of European Aviation/ATM business	10
1.4. European Union landscape for AI in aviation/ATM	13
2. AI: ALREADY IN THE SKY	14
2.1. AI in action in aviation	14
2.2. Existing data sharing initiatives	16
2.3. Lessons learned	16
3. ACCELERATING THE EMERGENCE OF AI IN EUROPEAN AVIATION/ATM	18
1. Foster data sharing for AI	19
2. Federate an aviation/ATM AI-specific infrastructure	19
3. Develop a new Joint Human Machine System, skills and training	19
4. Guarantee the safe use of AI	19
5. Master AI to remain cyber resilient	19
6. Build up an inclusive AI aviation/ATM partnership	19
4. FOSTER DATA SHARING FOR AI	20
1. Data governance	21
2. Data quality and data management standard for AI	21
3. Data collection	21
5. FEDERATE AN AVIATION/ATM AI-SPECIFIC INFRASTRUCTURE	23
6. DEVELOP A NEW JOINT HUMAN MACHINE SYSTEM, SKILLS AND TRAINING	25
7. GUARANTEE THE SAFE USE OF AI	29
7.1. AI can improve safety	30
7.2. More R&D is needed on AI certification	30
7.3. Safety culture, just culture and liability	32
7.4. Licensing-like certification	32
8. MASTER AI TO REMAIN CYBER RESILIENT	34
8.1. Improve cyber resilience with AI	35
8.2. Respond to new AI threats	36
9. BUILD UP AN INCLUSIVE AI AVIATION/ATM PARTNERSHIP	38
10. FLY AI: AN ACTION PLAN FOR EUROPEAN AVIATION	40
ANNEX 1: EUROPEAN UNION LANDSCAPE FOR AI IN AVIATION/ATM FURTHER EXPLAINED	44
ANNEX 2: CATALOGUE OF AVIATION/ATM AI-BASED APPLICATIONS	55
LIST OF PARTICIPANTS	74

FOREWORD

This report was developed by the **European Aviation/ATM AI High Level Group** (EAAI HLG). This High Level Group is composed of key representatives from all aviation sectors (airlines, airports, Air Navigation Service Providers, manufacturers, EU bodies, military and staff association). They joined forces to agree a common way forward to help demystify and accelerate the uptake of artificial intelligence in aviation/ATM i.e. on all ATM aspects in a wider sense including the ATM aspects of U-Space and avionics. Note that the document does not express EDA nor NATO official views.

The vision of the European Aviation/ATM AI High Level Group on AI for Aviation/ATM is that:

"European Aviation/ATM industry and European Network operations shall rely on
"Trustworthy Human Centric AI" solutions to:

- improve its operational performances and international competitiveness
- support the realisation of recent EU initiatives focusing on aviation/ATM digitalization, including the:
 - Digital European Sky;
 - SES Airspace Architecture Study; and
 - European ATM Master Plan, notably its automation vision.

The High Level Group's mission focusing on civil and military ATM business-to-business (B2B) activities, was multifold

- Help demystifying AI to a wider aviation community;
- Highlight key fundamental implications for industries and public entities, civil and military, when setting up their AI internal strategies, along with implications, interdependencies and responsibilities;
- Identify gaps and limitations for a broader adoption of AI in the full range of aviation/ATM operations;
- Identify changes to the framework necessary for strengthening AI in European aviation and in particular the Network Management;
- Accelerate, and intensify AI development and to promote its use in aviation; and
- Develop joint concrete recommendations and a corresponding action plan.

As AI knowledge and developments evolve, the EAAI HLG will ensure the regular update of its report for the benefit of the European aviation/ATM community.

MESSAGE FROM ADINA VALEAN

EUROPEAN COMMISSIONER
FOR TRANSPORT



The succession of remarkable innovations witnessed by aviation have brought us modern air travel, often referred to as 'the business of freedom'. The result is that more of us are travelling by air, and thankfully safer than ever before.

Innovations have meant amazing accomplishments in aircraft technology and air traffic control (ATC) operations. However, in comparison with the world around us, where rapid change is being powered by the broad availability of internet and an ongoing digital revolution, the aviation industry has been slower to take up technological, and in particular, digital innovations. With European aviation facing growing pressure to reduce its environmental impact, as well as persistent capacity bottlenecks, we need more sophisticated changes on the ground and in the air, and quickly, if we want to accommodate sustainable traffic and passenger growth. Artificial Intelligence (AI) can be a key ally in pursuit of this goal.

AI is revolutionising the technology landscape, and will usher in far-reaching changes for both businesses and society. Millions of Europeans are expected to benefit. At the same time, AI poses challenges of a technological, safety, security, ethical and legal nature. In February 2020, the Commission published a White Paper on fostering a European ecosystem of excellence and trust in AI.

The European Aviation Artificial Intelligence High Level Group brought together representatives from the public and private sectors, including EU bodies, international aviation organisations and aviation industry representatives, to develop a roadmap and practical recommendations to accelerate the acceptance of AI in the aviation sector, and in particular for ATC operations.

This report is the first of its kind for this safety-critical sector, in which various levels of automation are already present, alongside massive data streams. It shows that AI is being trialled extensively, and increasingly introduced into service provision. It is now important to exploit these new technologies, more rapidly than has been the case up until now, to address airspace capacity shortages, optimise aircraft trajectories, boost punctuality and support decision-makers, pilots and air traffic controllers.

The report can be seen as a catalyst. It should focus efforts and spur innovation so that we may overcome the main challenges facing the industry, and improve the passenger experience in a safe and resilient manner while adhering to ethical principles.

I look forward to seeing the sector making good use of the report's roadmap and recommendations.

A handwritten signature in blue ink that reads "Adina Valean".

MESSAGE FROM EAMONN BRENNAN

DIRECTOR GENERAL OF
EUROCONTROL



The aviation sector will only be able to embrace the full potential of Artificial Intelligence if all actors join forces, and do so urgently. This was the key takeaway from EUROCONTROL's inaugural conference on AI in aviation back in May 2019, and led to EUROCONTROL, together with the European Commission and a wide range of partner organisations, agreeing to set up a European Aviation High Level Group on AI.

This comprehensive "FLY AI" report is a major output from the Group, and I would like to congratulate all participating organisations for producing such a rich and extensive analysis of AI in our sector. It puts into perspective progress made already, and demonstrates that by joining forces, we will be in a position to accelerate AI development, and unlock its potential for the benefit of the whole community and the European Network in particular. It is also particularly timely, complementing EASA's recently published Artificial Intelligence Roadmap, which focuses on safety and ethical dimensions of AI in aviation.

I would like to thank the large number of partner aviation/ATM organisations who supported us in producing this report. The work already underway, and the clear potential for the future, fills me with confidence that by continuing to collaborate and following the practical recommendations in this report, we will strengthen the potential of AI and witness an increasing deployment of AI solutions across aviation.

A handwritten signature in black ink that reads "Eamonn Brennan". The signature is fluid and cursive, with "Eamonn" on top and "Brennan" below it, both starting with a capital letter.

EXECUTIVE SUMMARY

Artificial intelligence (AI) is already starting to transform how the world lives and works, and the pace of AI deployment is currently rapidly accelerating. In a world increasingly driven by big data, and with massive developments in recent years in computing power and advanced algorithm use, AI will play a major role in all industrial sectors, driving competitiveness and productivity, and offering, if correctly deployed, huge economic and societal advantages. In the global race to achieve a crucial advantage in innovation, Europe needs to keep pace with other actors which are leading the way in AI development, which is why the European Union has declared AI to be a major strategic priority. At the same time, the EU also aims to ensure that European AI developments are also safe, secure, human-centric, ethical, and trustworthy and support the core values of the EU.

As a sector, aviation and air traffic management (ATM) is ideally placed to take full advantage of AI, in particular machine learning. ATM is powered by air to ground and ground to ground data flows – and ‘big data’ is a prerequisite for the successful use of AI. Indeed, AI and machine learning are already contributing to a wide spectrum of value opportunities in the aviation/ATM industry, from efficiency-focused to safety critical applications. AI has huge potential for use in areas where it can reduce human workload or increase human capabilities in complex scenarios, e.g. to support air traffic controllers (ATCOs), pilots, airport operators, flow controllers or cybersecurity officers. AI will also play a fundamental role in driving the development of new ATM/U-space services as new airspace users (high-level vehicles, low-level drones) further complexify the existing use of airspace. AI will also increase safety through the provision of new conflict detection, traffic advisory and resolution tools as well as cyber resilience. As aviation actors increasingly embark on digital transformation journeys, AI represents a potential breakthrough technology, capable of transforming the aviation/ATM industry value chain. In particular, AI will enable better use of aviation data leading to more accurate predictions and more sophisticated tools, increased productivity and enhanced use of scarce resources (e.g. airspace, runways, staff), helping both tackle capacity and environmental impact, the twin major challenges facing aviation today.

However, the full potential of AI is far from being harnessed across Europe or in aviation/ATM. While there are many AI success stories, they remain limited in scope. Understanding of how AI can generate business and societal value remains in its infancy, and expertise is scarce.

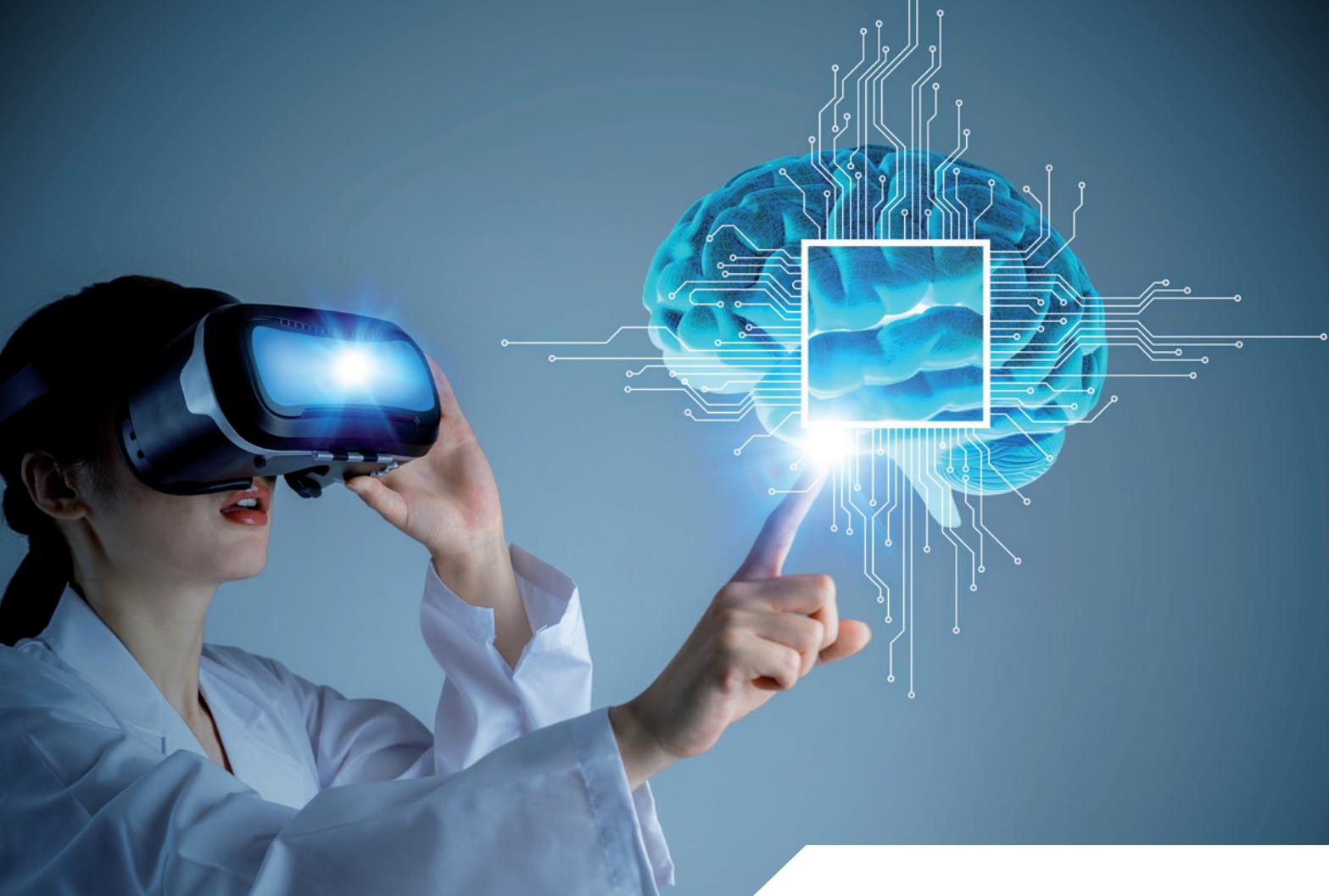
In recognition of these challenges, EUROCONTROL together with the European Commission and a wide range of partner organisations took the decision to set up a European Aviation High Level Group on AI (the EAII HLG) with the goals of advancing understanding among aviation/ATM actors of AI and its potential, demystifying the topic, and helping accelerate the uptake of AI in our sector.

To help drive AI forward, we conclude with a practical “FLY AI Action Plan” with a series of recommendations, notably to create a federated AI infrastructure containing historical data for training purposes and to develop AI applications, together with an appropriate governance structure; to accelerate the deployment of AI notably in the areas of cyber and non-safety-critical applications, to conduct more AI research and development in particular to help respond to the safety-criticality of aviation/ATM operations, to foster the emergence of an AI Culture through training and re/upskilling of staff across enterprises; to foster partnerships with other Digital Innovation Hubs, AI specialists and other industrial sectors; and to facilitate and increase experience/knowledge sharing, communication and dissemination.

The report is structured as follows. Section 1 provides a short overview of AI, and how the expected business advantages it can offer to European aviation/ATM. Section 2 examines current experience with AI in aviation/ATM, detailing a wide spectrum of already developed or deployed AI-based applications in the European aviation/ATM domain as well as the current European AI-related policy and R&D framework (the two annexes to the report complement this, with Annex 1 describing the EU landscape, and Annex 2 providing a detailed list of projects and initiatives). Section 3 proposes a range of actions that could be taken to accelerate the development of AI in European aviation/ATM. Sections 4 to 9 develop the six accelerators for the uptake of AI in aviation/ATM. Finally, Section 10 summarises with a proposed “FLY AI Action Plan”, gathering all the recommendations made throughout sections 1-9.

RECOMMENDED ACTIONS

Data and AI-infrastructure framework	<ul style="list-style-type: none"> ■ A federated data foundation and AI-infrastructure should be established
Research and Innovation	<ul style="list-style-type: none"> ■ Further exploration of the potential of AI in aviation/ATM should be strengthened in areas of: <ul style="list-style-type: none"> ■ high impact on aviation/ATM performance and environment ■ human-machine collaboration ■ safety-critical operations ■ safety intelligence tools and cyber threat intelligence services
Validation and Standards	<ul style="list-style-type: none"> ■ Appropriate AI validation methods and tools should be developed as well as standards and guidelines
Deployment	<ul style="list-style-type: none"> ■ The rapid uptake of AI-based solution in operations should be encouraged in the cybersecurity domain and non-safety critical operations ■ European aviation/ATM actors should aim to reduce AI-developments time to market.
Communication and Dissemination	<ul style="list-style-type: none"> ■ Communication on AI should be enhanced ■ Dissemination of AI benefits and lessons learned should be strengthened ■ AI aviation/ATM applications developments and deployments should be regularly scouted
Training and Change Management	<ul style="list-style-type: none"> ■ An AI culture through training/re/upskilling and change management should be developed
Partnership	<ul style="list-style-type: none"> ■ The aviation/ATM community should build-up an inclusive AI aviation/ATM partnership



1. ARTIFICIAL INTELLIGENCE (AI) – SETTING THE SCENE

1.1. AI AND MACHINE LEARNING DEFINITIONS

Since the term “artificial intelligence” was first used in 1956, considerable research and development has been conducted into the ability of systems to perform tasks by simulating human intelligence processes, with significant acceleration of progress in recent years. A useful starting point for this report is the comprehensive definition of AI system made

by the High-Level Expert Group of Artificial Intelligence established in 2018 by the European Commission (AI HLEG)¹:

Artificial intelligence (AI) refers to systems that display intelligent behaviour by analysing their environment and taking actions – with some degree of autonomy – to achieve specific goals. AI systems are software (and possibly also hardware) systems designed by humans that, given a complex goal, act in the physical or digital dimension by perceiving

¹ <https://ec.europa.eu/digital-single-market/en/high-level-expert-group-artificial-intelligence>

their environment through data acquisition, interpreting the collected structured or unstructured data, reasoning on the knowledge, or processing the information, derived from this data and deciding the best action(s) to take to achieve the given goal. AI systems can either use symbolic rules or learn a numeric model, and they can also adapt their behaviour by analysing how the environment is affected by their previous actions.

As a scientific discipline, AI includes several approaches and techniques, such as machine learning (of which deep learning and reinforcement learning are specific examples), machine reasoning (which includes planning, scheduling, knowledge representation and reasoning, search, and optimization), and robotics (which includes control, perception, sensors and actuators, as well as the integration of all other techniques into cyber-physical systems)

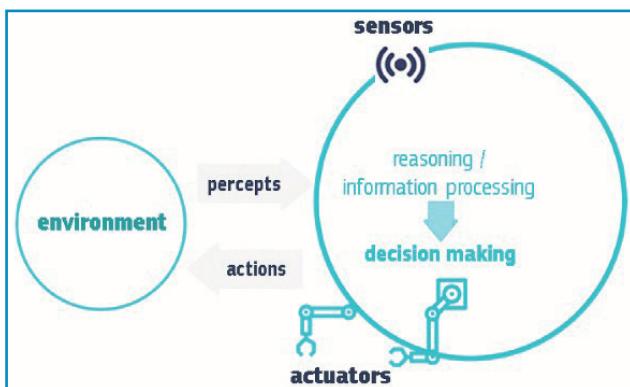


Figure 2: AI system

Machine learning (ML) refers to the ability of algorithms to learn. It is a subset of Artificial Intelligence (AI) comprising algorithms able to model systems by learning from the input and output data that characterize them. This is done automatically through specific strategies. Once the models are adjusted after training, they are able to predict the outcome of any input, even if it has not been processed before. ML can be provided by different kind of algorithms like neural networks, decision trees, inductive logic programming or Bayesian networks among others.

An AI-based system, therefore, can be seen as one that provides outputs that mimic human intelligence. AI is particularly good at analysing large and highly detailed historic datasets and quickly deriving complex data relationships that exceed the computational capacity of the human brain. Thus, AI is extremely valuable in areas where it can reduce human workload or increase human capabilities in complex scenarios, and every industry is now exploring

where AI can be most effectively used e.g. to support ATCOs, pilots, airport operators, or cybersecurity officers.

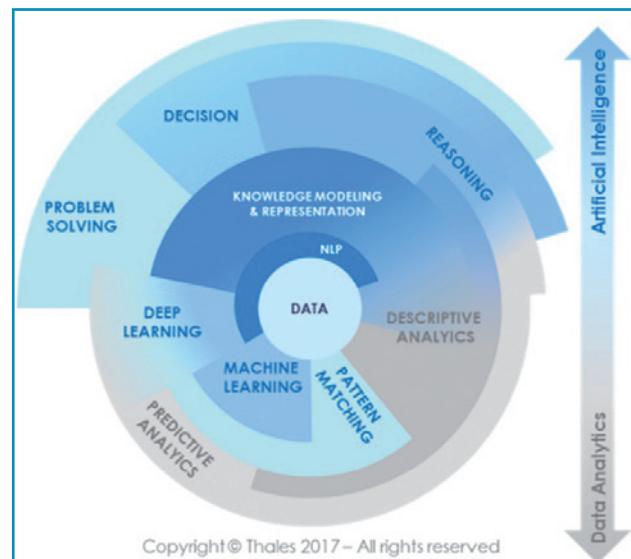


Figure 3: Spectrum of AI technologies

AI has developed significantly from the simple logic-based approaches of the 1950s, powered by the development of algorithms, massive advances in computing power, and the availability of ever-increasing masses of data. Figure 4 provides a helpful visualisation of some of the key technological breakthroughs over the past two decades.

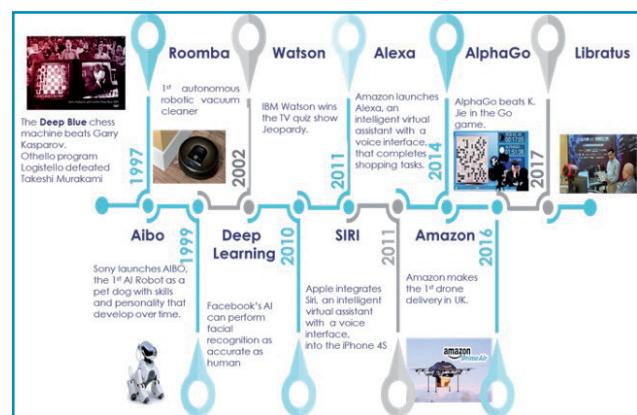


Figure 4: AI worldwide recent developments

1.2. AI IN EUROPE

Given its potential to transform how we live and work, the further development of AI is a major strategic priority for Europe.

Many large European corporations have already implemented aspects of AI technology successfully. However, AI adoption is significantly lower among small and medium-sized enterprises (SMEs), which are less sure about the difference that AI could make to their business, and/or lack the resources to investigate AI further.

The degree to which European companies are adopting AI, and the impact that AI and related technologies (robotics, automation in general, machine learning, etc.) are having on the European economy are now being monitored by the European Commission's Joint Research Centre (JRC) and the European DIGITAL SME Alliance, which have teamed up to form a Focus Group on Artificial Intelligence. This group is tasked with defining the current state of adoption and use of AI, and with following over the next three to five years how and what changes through the introduction of tools linked to AI (for example, its impact on management and data integration, production, support or management processes), and the social and economic impacts of these changes (e.g. skills, recruitment, employer-worker relations).

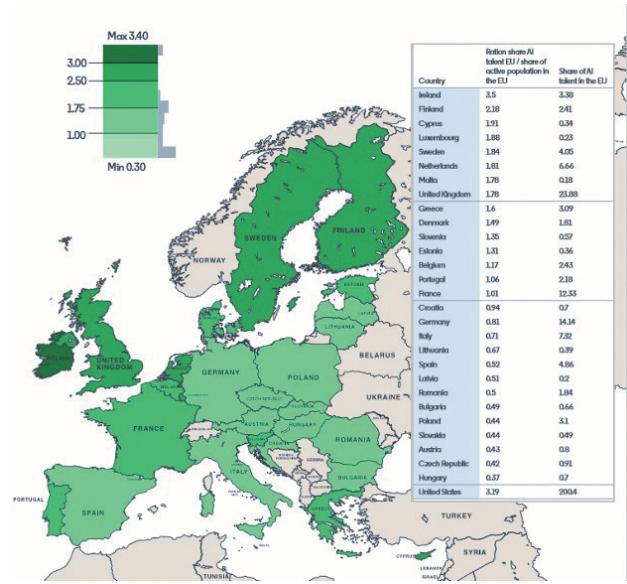


Figure 6: AI intensity in the European Union

This is an excellent initiative, and this report considers that it would be highly beneficial to the aviation/ATM community to monitor AI development in a similar way in the aviation sector, and join forces.

The number of experts working on AI varies significantly across EU Member States, according to a recently published LinkedIn study² on "AI Talent in the European Labour Market". To understand how capable countries are of developing or attracting AI talent, they have developed an 'AI intensity' ratio, which compares the number of AI experts against the size of the active working population in each country. The result is depicted in Figure 6.

Mapping AI intensity confirms that there is a clear East-West divide within the EU, with six countries – Ireland, Finland, Cyprus, Luxembourg, Sweden and the Netherlands – leading the EU in attracting or developing AI talent. Among these Ireland stands out, potentially reflecting the strong presence of technology companies in the country.

The uneven distribution of AI intensity in Europe shows that while progress is being made with AI implementation, there is a long way to go before this is more evenly distributed. To maintain competitive advantage, Europe clearly needs to move faster on AI implementation to avoid lagging behind other world regions in the future, especially China and the US.³

1.3. AI IN SUPPORT OF EUROPEAN AVIATION/ATM BUSINESS

The ability of AI to identify patterns in complex real-world data that human and conventional computer-assisted analyses struggle to identify makes AI extremely well-suited to the aviation sector, which is increasingly dependent on electronic data flows between air and ground systems.

AI additionally has the potential to transform aspects of the aviation sector, enabling ATM functions to be performed in entirely different ways in the future. While the full potential of AI for aviation will only emerge over time, it is already the case that the availability of data, advanced algorithms and massive increases in computing power means that AI can already offer genuine advances to Aviation/ATM.

2 <https://economicgraph.linkedin.com/research/ai-talent-in-the-eu> (Nov 2019)

3 The center for data innovation's report on "who is winning the AI race : China, the EU or the United States" identifies that the US is first with 44.2 points , followed by China (32.3) and further down the EU with 23.5 out of 100 points, addressing 6 categories of metrics : talent, research, development, hardware, adoption and data. <https://www.datainnovation.org/2019/08/who-is-winning-the-ai-race-china-the-eu-or-the-united-states/>

4 The safety-criticality of non-traditional SW elements denotes any software including AI and adaptive algorithms that command, control and monitor safety-critical functions for aviation/ATM.

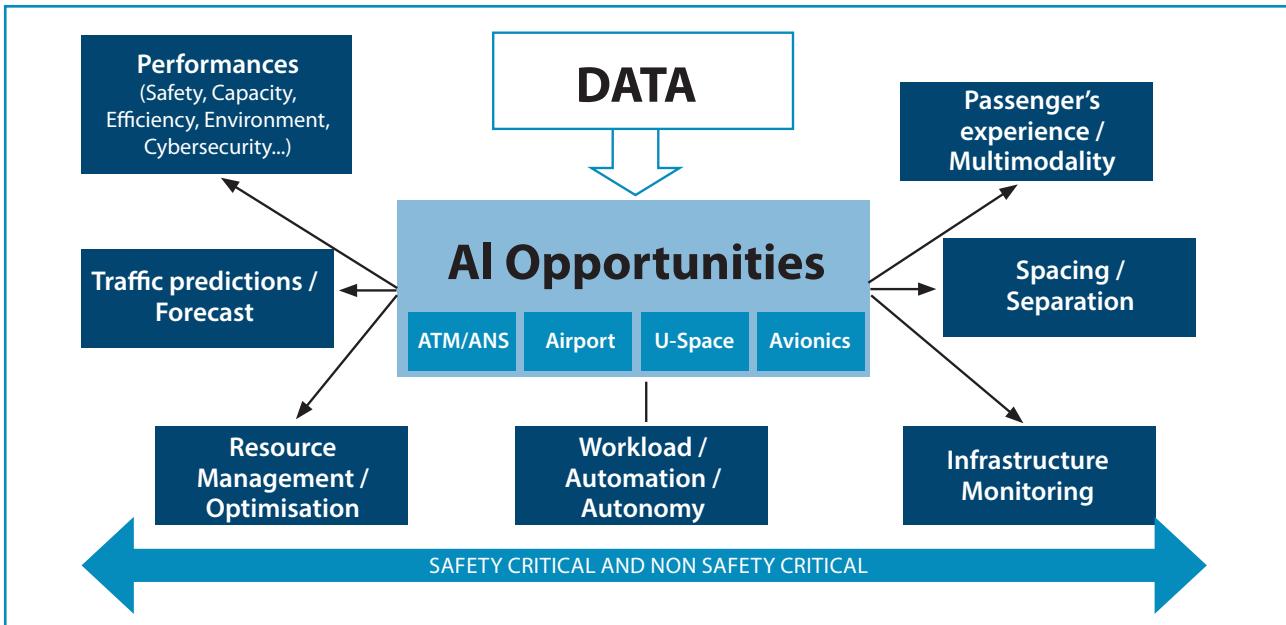


Figure 7: Key areas of AI opportunities for aviation/ATM

As Figure 7 above shows, AI/Machine Learning (ML) are already contributing to a wide spectrum of value opportunities in the aviation/ATM industry, from non-safety-critical to safety-critical applications⁴. Another transversal component is AI-enabled simulation platforms, where augmented reality offers the possibility of creating a testing and validation environment where new and innovation aviation concepts like U-space can be explored.

These AI opportunities can be used to address a number of current and future challenges in aviation/ATM, of which four stand out:

1. HELPING MITIGATE THE ‘CAPACITY CRUNCH’

The network handled 11.1 million flights in 2019, up 0.9% for the full year against 2018. Thanks to a collective effort led by the EUROCONTROL Network Manager (NM)⁵ together with a range of partners (air navigation service providers, airlines and the military), the NM was able to mitigate the capacity crisis and reduce the level of delays. En route delays declined by 8% to 17.5 million minutes of delay (compared to 19 million minutes in 2018), generating an average delay per flight of 1.57 minutes. However, with average delays per flight 88% worse than in 2017, and with traffic forecast to increase steadily over the coming years, there is a real ‘capacity crunch’ facing Europe’s crowded skies and increasingly congested airports. By 2040, EUROCONTROL-ACI’s Challenges of Growth study notes that 1.6 million passengers could be left without a flight in the absence of significant structural change.⁶

In addition to measures already being explored - defragmentation of airspace, better staff rostering, more efficient use of runways, deployment of key enablers such as data link, and so on – AI could also play a fundamental role.

AI will help address capacity issues in ATM by enabling better use of data, leading to more accurate predictions and more sophisticated tools, increased productivity and enhancing the use of airspace and airports. Moreover, by better understanding the extent of the challenges, AI will be able to come up with innovative responses based on non-straightforward correlations of parameters. Finally, AI has the potential to improve the scalability, efficiency and resilience of the system.

2. FACILITATING HIGHER LEVELS OF COMPLEXITY

Increased traffic levels and new airspace users (e.g. very-high altitude operations, next-generation supersonic commercial aircraft, military RPAS as well as drones operating in U-space), combined with diverse communication technologies, flight and speed patterns, will lead to unprecedented levels of heterogeneity and complexity, requiring further automation, connectivity and interoperability of the aviation ecosystem.

The rapidly developing drone industry in particular will pose a significant ATM integration challenge, with a large number

⁵ EUROCONTROL has been appointed as Network Manager for air traffic network functions of the Single European Sky since 2011. On 6th May 2019, the European Commission reappointed EUROCONTROL as the Network Manager from 2020 until 2029.

⁶ <https://www.eurocontrol.int/sites/default/files/content/documents/official-documents/reports/challenges-of-growth-2018.pdf>

1. Artificial Intelligence (AI) – Setting the Scene

of heterogeneous unmanned aerial vehicles operating at all levels, complicating the handling of conventional manned aircraft. Autonomous flying, including avionics system sensors, inherently rely on AI for the reliable, real-time processing of recognition of objects around the aircraft or drone. At the same time, interest is growing in operating vehicles at very high altitudes, thus extending air traffic management (ATM) to altitudes currently not occupied in the stratosphere, and increasing congestion in already saturated transition areas.

Moreover, as the European ATM Master Plan and the SES Airspace Architecture Study emphasise, a fundamental shift is expected in the form of increased levels of automation at the strategic, pre-tactical and tactical layers of traffic management (for both ATM and Unmanned Traffic Management (UTM); this shift is in particular expected to support the transition from airspace-based to trajectory-based operations. The work of air traffic controllers has benefited from increasing automation over the past decades. This automation is based on additional available data and new assistance systems, e.g. Medium Term Conflict Detection (MTCD), Minimum Safe Altitude Warning (MSAW), Controller Assistance Tools (CATO). The use of AI/machine learning in these systems is a reasonable future option, but one that still requires significant research and development effort.

AI will become a useful assistant to all ATM actors from planning to operations and across airspace users. Additionally, AI will drive the development of new ATM/U-space services, and will increase safety through the provision of new conflict detection, traffic advisory and resolution tools as well as cyber resilience.

3. RESPONDING TO THE CLIMATE URGENCY

The top priority for the European Commission over the 2019–2024 period is the Green Deal. Its overall aim is for Europe to become the world's first climate-neutral continent by 2050. This is the greatest challenge and opportunity of our times, and this is particularly true for the aviation sector.

In the ECAC area, in 2019 versus 2017, number of flights grew by 4.54%. While aviation CO₂ emissions, grown by 9%, have increased by twice as much as traffic over the past two years, excess CO₂ emissions due to ATM inefficiency⁷ has remained roughly stable at 6%⁸. To reach the EU's carbon neutral goal by 2050, the aviation sector must develop a response to improve the structural capacity of European airspace core area, balancing the need to meet business and societal needs for mobility with the pressing goal of reducing aviation's environmental footprint and meeting societal expectations in terms of climate change and health. With these two apparently

contradictory requirements, we are in real need of a disruptive, innovative and fundamentally different approach.

By accelerating the digital transformation in terms of optimising trajectories, creating 'green' routes and increasing prediction accuracy, AI could make a real difference to mitigating the environmental impacts of aviation, also in addition to providing decision-makers and experts with new features that could transform the ATM paradigm in terms of new techniques and operating procedures and greater efficiency.

4. ENABLING DIGITAL TRANSFORMATION

Digital transformation is at the heart of the European ATM Master Plan. In its recently published blueprint⁹, the Digital European Sky aims to leverage the latest technologies to transform Europe's aviation infrastructure, enabling it to handle the future growth and diversity of air traffic safely and efficiently, while minimising the environmental impact. Central to this digital transformation are increased levels of automation, cyber-secure data-sharing and connectivity. Moreover, AI will enable the virtualisation of infrastructure and air traffic service provision in all types of airspace, ranging from very low to high altitude operations. In doing so, these technologies will enable the system to become more modular and agile, while building resilience to disruption, traffic growth and greater airspace user diversity.

AI is a breakthrough technology that could radically influence or transform the aviation/ATM industry value chain, potentially impacting all stakeholders, including original equipment manufacturers (OEMs) and their business models. The impact of transformative AI will be felt throughout the industry, and beyond.

The products and services made possible by the use of AI will not only impact the business of all incumbent and traditional industry competitors, but will also open the market up to new entrants. As a result, a new ecosystem of players is emerging. New players will be important partners for traditional aviation companies. While aviation/ATM actors can use their technological expertise to unlock value potential from AI, these new players will have multiple opportunities to penetrate the aviation and mobility markets.

In conclusion, the potential for AI is huge, if the industry takes action and fully captures AI-enabled value opportunities in both the short and long terms.

⁷ 2020 Update of the ATM Chapter of EAER2019

⁸ <https://ec.europa.eu/transport/sites/transport/files/2019-aviation-environmental-report.pdf>

⁹ https://www.sesarju.eu/sites/default/files/documents/digital_european_sky_blueprint.pdf

1.4. EUROPEAN UNION LANDSCAPE FOR AI IN AVIATION/ATM

The EAAI HLG has conducted an in-depth review of the existing European policy and research & innovation (R&I) framework related to AI for aviation/ATM. By doing this, the group was able to avoid any duplication of actions, benefit from existing material, and identify any missing initiatives in the domains of policy/regulation, capacity building or partnership that could help address identified AI aviation/ATM challenges. Figure 8 brings together the most relevant European AI and aviation/ATM initiatives which have a direct link with AI (each initiative is further detailed in Annex 1).

The findings of the review show that while there is not yet a holistic initiative on AI in aviation/ATM, two threads of developments can be identified: 1) the European Trustworthy Human-centric AI (depicted in blue) and (2) the aviation/ATM AI framework (depicted in dark blue).

The first aims to strengthen and drive the development of AI in European industry and for European citizens, and to do so in a way that respects European values. It is sector-agnostic and thus not customised to aviation/ATM specificities. However, it offers a set of essential principles together with a range of AI tools, products and services that

could be reused and prove highly beneficial in the aviation/ATM sector.

The second foresees AI primarily as a key enabler of the Digital European Sky. As already highlighted, many developments (including EASA and EUROCAE) are taking place. Still, many of the ATM digitalization initiatives do not yet have a strong focus on AI and remain fragmented.

Within the SESAR and H2020 R&I framework, as well as through aviation/ATM industrial R&D effort, AI-based solutions have been developed alongside an appropriate data-sharing infrastructure. Some of them have been further integrated into an operational environment and fast tracked, and are now fully operational. While further research is still required, there is now a need to strengthen AI development efforts towards deployment and operation, and deliver AI benefits to the aviation/ATM community and passengers.

Based on the above, to accelerate the use of Trustworthy Human-centric¹⁰ AI in Aviation/ATM, there are two main options: 1) develop further the AI ecosystem for European aviation/ATM in a self-contained aviation/ATM framework, or 2) customise AI initiatives to aviation/ATM. The way forward was to combine those two options, bridging the aviation/ATM community to the AI community and optimising the reuse of AI tools, products and services.

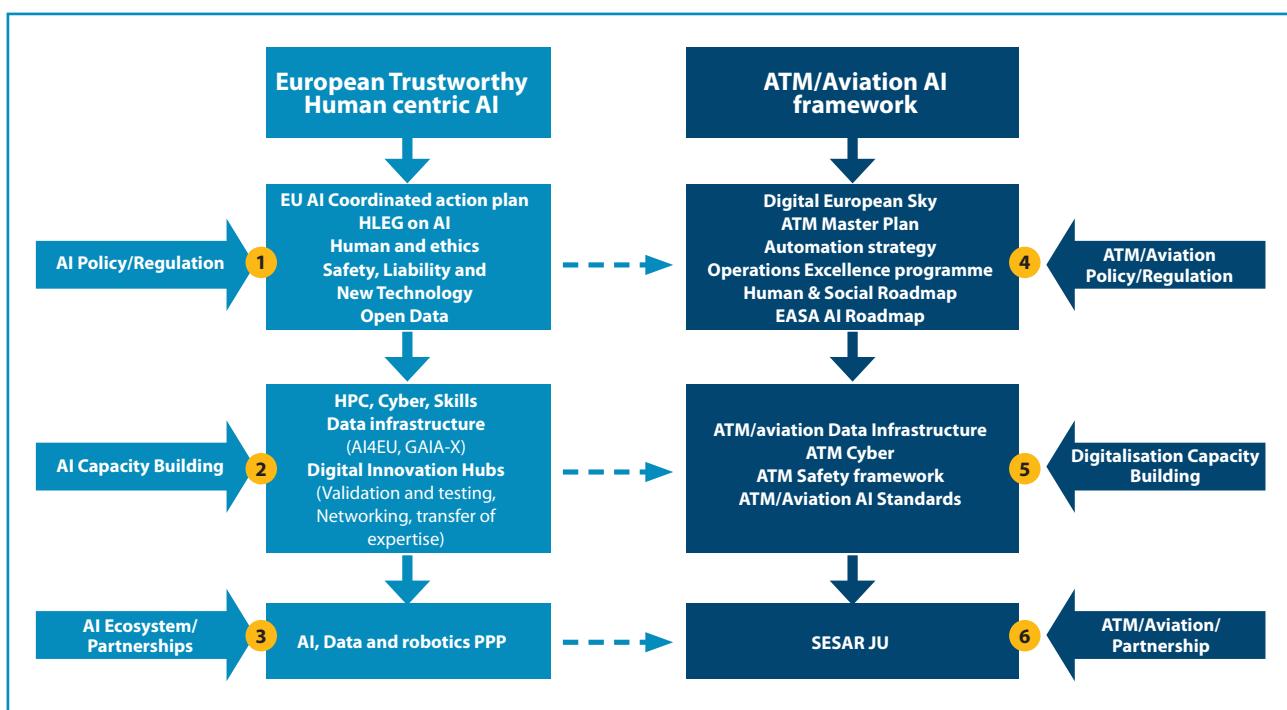


Figure 8: European Union landscape for AI in Aviation/ATM

¹⁰ 'Trustworthy AI' concerns not only the trustworthiness of the AI system itself, but also comprises the trustworthiness of all processes and actors that are part of the system's lifecycle. Hence, they are lawful, ethical and robust.



2. AI ALREADY IN THE SKY

2.1. AI IN ACTION IN AVIATION

One of the most frequently encountered use of AI in aviation is machine learning, and aviation stakeholders are actively developing a range of such applications in ATM, airport-related systems and avionics, most of which directly aim at improving real-world performance. Annex 2 of this report catalogues more than 20 aviation/ATM

applications, giving a good indication of the large spectrum of applications already in place or under development, and the significant improvements machine learning can bring. Table 1 summarises the main aims and benefits of the AI applications of the catalogue, while Figure 9 shows their level of maturity.

AREA	BENEFITS	ANNEX 2 ITEM
Traffic predictions / forecasts/modeling	1. Improving predictions of aircraft trajectories, reducing uncertainty and increasing capacity	2,5,7,9,23
Resource management / Optimisation	1. Deploying the optimal configuration of sectors and thus optimising capacity with the available resources 2. Supporting ATM demand and capacity balancing	10,11 15
Workload / Automation / Autonomy	1. Reducing ATCO workload (e.g. using speech recognition models for controller assistance) 2. Reducing risks with safety intelligence tools ¹¹	14,17,19, 20,21
Airport performance	1. Improving runway throughput (e.g. ROT prediction, improving spacing buffers) 2. Cutting airport delays	6,12,13,14,16, 20,22
Passenger experience	1. Improving passenger transfer/ customer satisfaction 2. Using biometrics to accelerate secure boarding	1,23
Infrastructure monitoring	1. Improving GNSS monitoring 2. Cybersecurity monitoring	4 18
Airborne capabilities	1. Improving validation capabilities 2. Generating environmental improvements 3. Pilot and ATCO assistant through automatic speech recognition 4. Enhancing safety with automatic taxi, take-off and landing enabled by computer vision	3 8 17 23
Airline performance	1. Optimising fuel usage 2. Proposing better and more routes	3 5

Table 1: Aims and benefits of the AI applications of the catalogue

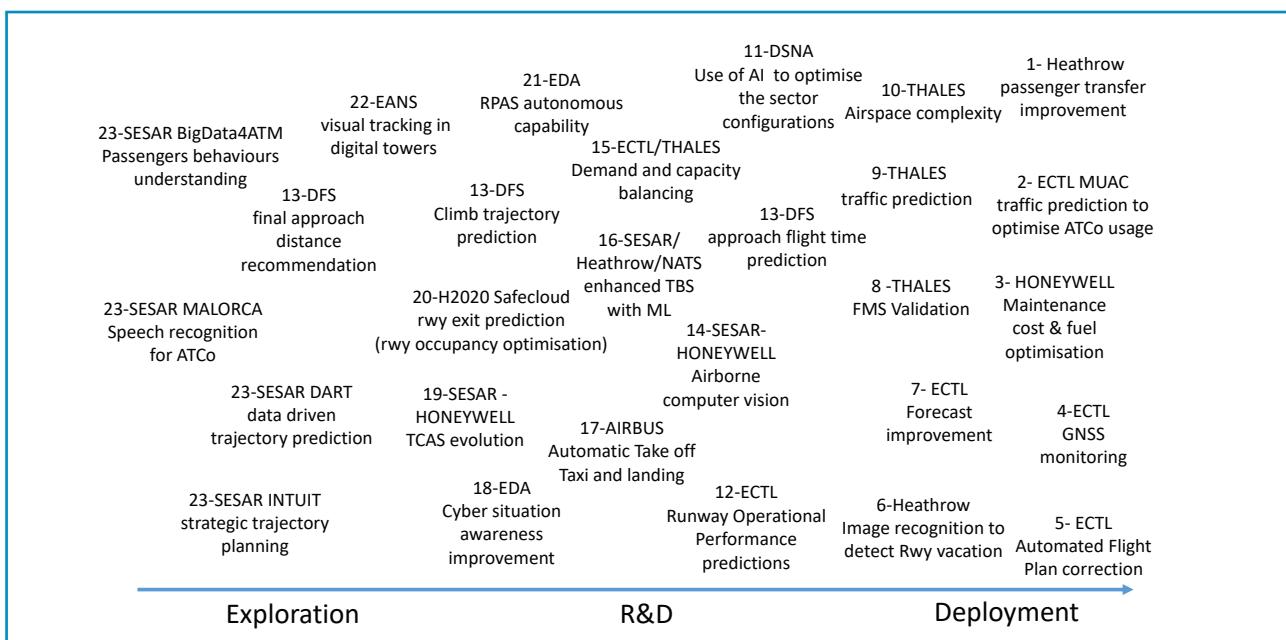


Figure 9: Maturity assessment of selected aviation/ATM AI applications

¹¹ ACARE SRIA Safety and security : action area 4.3Build and exploit safety intelligence : <https://www.acare4europe.org/sites/acare4europe.org/files/document/ACARE-Strategic-Research-Innovation-Volume-1.pdf>

2. AI: Already in the sky

In the emerging area of drones, which lacks extensive historical data, AI developments are primarily focused on ‘detect and avoid’, precision navigation, and image recognition.

A number of the considered applications are already in operation (e.g. EUROCONTROL’s Maastricht Upper Area Control Centre (MUAC) has already demonstrated the safety of its pre-tactical traffic prediction¹² tool powered by AI, for the purpose of flow and capacity management prior to entry of the flight in its airspace). In all of these already deployed AI-based applications, the role of the operator has not changed significantly; in fact to the contrary, often his/her task has been facilitated and operational performance has improved as a result of deploying AI.

Interestingly, the development of these AI applications was in all cases extremely fast, often less than two years from concept to implementation. This was indeed facilitated by the non-safety criticality of such applications.

2.2. EXISTING DATA SHARING INITIATIVES

As an increasingly data-driven industry with technical systems dependent on numerous data flows, ATM produces a considerable volume of data, and sharing this data among aviation/ATM stakeholders for operational purposes is already happening:

- EUROCONTROL distributes widely air traffic flight and flow information as well as European airspace structures using the EUROCONTROL NM B2B Web Services
- Aircraft trajectories are displayed on freely accessible websites and apps globally, enabling passengers and enthusiasts to track flight schedules and individual aircraft
- Flight schedules for every reason are available to purchase at the start of each season
- Aviation/ATM data/services (e.g. MET) are already shared among stakeholders under SWIM data-sharing framework
- In Europe, Commission Regulation (EU) No 255/2010 (common rules on air traffic flow management) lays down the principles of very large-scale data exchange for the execution of ATM. European law defines a set of obligations in term of data for ATM stakeholders: air navigation service providers (ANSPs), airports, airlines, etc. This is a tangible example that ATM data are accessible and distributed 24/7 for the benefit of the European air navigation network

- EASA has launched the DATA4SAFETY programme sharing aviation data to help analyse trends and situations which can lead to a safety hazard

Data are key to the success of AI uptake, which depends to a very large extent on the ability to share data in order to obtain the largest possible datasets.

2.3. LESSONS LEARNED

As illustrated in the catalogue of applications and the data sharing initiatives, AI is already being used in aviation/ATM today, with promising results starting to be delivered in various aviation/ATM areas.

Some lessons can already be drawn from experience with AI to date:

- **AI tools need access to large volumes of data:** Applying AI to help resolve key challenges relies on a fundamental prerequisite: big data. Although the aviation/ATM sector produces significant amounts of data, in the absence of appropriate data governance and data sharing frameworks, aviation data remain fragmented across stakeholders, and this is hampering further AI development.
- **No ‘one stop shop’ to access ATM data:** Data are kept by data collectors which often are not the owners of the data. AI developers have experienced great difficulties in trying to access even partial datasets.
- **Gathering large amounts of ATM data poses a wide range of difficulties:** There are a host of fundamental questions that need to be addressed, such as:
 - Protection of trade secrets
 - Data quality
 - Data validation and verification
 - Anonymisation
 - Data protection (confidentiality and cyber security)
 - Infrastructure and availability
 - Computational power.
- **Access to datasets is complex in the absence of clear data governance at industry level:** AI algorithms need to be tested on massive amounts of clean data sets reflecting real-life situations. These data sets come either from simulated data, or from historical data gathered over the years and captured in various databases. Addressing the legal aspects of data sharing is still very much an ad hoc process. Solutions were found for both the Safe Cloud project and the SESAR Digital Sky Challenge, for example, but both required a multiplicity of bilateral agreements to ensure anonymisation and privacy of shared data.

12 In this context, pre tactical traffic predictions are performed on the day of operation.

- **Data quality:** Combinations of multiple sources of data can improve significantly the quality of results and trust in them. While as much data as possible are required for robust results, it is also important to note that data quality and relevance are just as important as volume.
- **Use of historical data to build future scenarios:** When it comes to forecasting or developing new concepts/systems, using historical data to develop future scenarios represents a significant challenge.
- **A variety of techniques need to be explored, matured and validated:** AI and data science do not always work immediately, and it is often necessary to test extensively, add more data sources, and explore multiple techniques. It is also inadvisable to over-rely on machine learning, as even the most advanced AI algorithms can generate impossible results, and thus still require intensive human verification. In following the full technology innovation cycle, go/no-go decisions at each gate must be rapid and brutal; but developers need to be incentivised to try even if success is for a minority of attempts.
- **A combination of technology data and domain expertise is needed:** AI by itself is meaningless, and large data sets alone are insufficient without interpretational expertise. The combination of computational techniques, data and collaboration with experts is essential to successful AI deployment – ironically making human AI expertise a scarce resource essential for success.
- **End-user-centric development is key:** Users need to be involved from the earliest stages of development. Validation is 'fitness for purpose', and the purpose will remain to support users.
- **Careful assessment and validation is necessary:** New machine learning techniques need to be applied and assessed very carefully as they could affect safety, bring undesired outcomes due to undetected biases in the data – or fail to improve performance in a homogeneous way that could potentially negatively impact other parts of the aviation/ATM system.
- **Industrialisation of AI solutions:** This requires different setups and the development of new specific industrial processes.
- **Cyber concerns may impair AI developments if not addressed.** Some AI developments in other industry sectors have been stopped or delayed by the fear that AI could increase the vulnerability of systems to cyber-attack.

Although we are just at the implementation stage, initial results from initial AI developments including data sharing initiatives show that AI has the potential to become a vital element in the toolbox of aviation/ATM actors, playing their role as medium-term capacity enablers to the realisation of the Digital European Sky.

TAKE-AWAY

R&I

- **Strengthen further exploration and exploitation of the potential of AI** in aviation/ATM by launching research and innovation improvement actions, particularly in areas of high impact on aviation/ATM performance and environment.

Deployment

- **Speed up AI implementation:** To remain in the race in the face of rapid international developments in the field of AI, in particular in aviation/ATM, European aviation/ATM actors should aim to reduce significantly the time it takes to bring AI-developments to market. We need to think of each AI deliverable as an innovation that requires rapid implementation and could take significant steps forward in the way we operate aviation/ATM today.

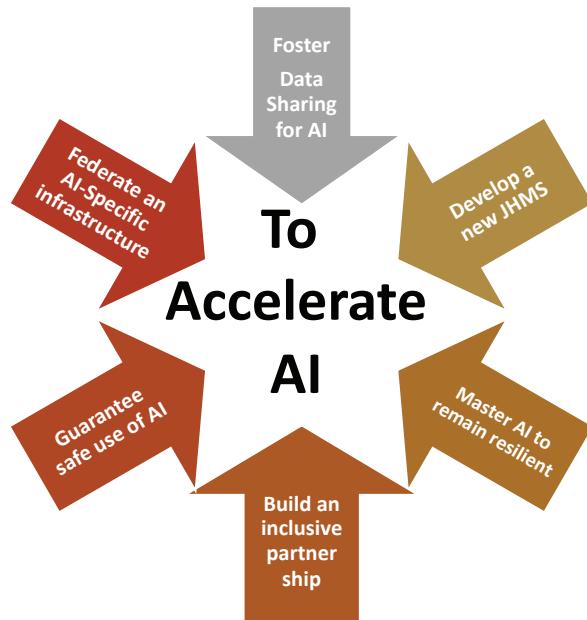
Communication and dissemination

- **A regular technology scouting of European AI aviation/ATM applications developments and deployments progress should be performed** and their (potential future) performance improvement should be assessed. To help further, we could also learn from AI developments in Europe in other sectors, as well as in those parts of the world where AI development is genuinely accelerating (e.g. China, the US and Canada).
- **Establish communities of practice** to share lessons learned develop guidelines based on best practices.



3. ACCELERATING THE EMERGENCE OF AI IN EUROPEAN AVIATION/ATM

Based on the lessons learned from these initial AI-based applications developments, the European Aviation AI HLG (EAAI HLG) has identified six accelerators responding to the remaining key challenges for the swift uptake of AI:



1. FOSTER DATA SHARING FOR AI

The aviation/ATM Lack of a data foundation framework: This has been apparent from the very first developments of AI, and will be developed further in section 4.

2. FEDERATE AN AVIATION/ATM AI-SPECIFIC INFRASTRUCTURE

There is no fully appropriate aviation/ATM AI-infrastructure that can cover the current and future requirements of AI-enabled applications. This action area is further elaborated in section 5.

3. DEVELOP A NEW JOINT HUMAN MACHINE SYSTEM, SKILLS AND TRAINING

The role of humans in AI will have to evolve: One of the most common misconceptions of AI is that AI, as a new form of intelligence, will ultimately replace the human, and that is undesirable in a human-centric and safety-critical business environment. How, AI's critics ask, can humans and automation form a well-performing team let alone achieve societal acceptance by both the general public society and by the system operators in question? What are the best transition strategies? Precisely how these fears can be overcome, and allow AI to bring benefits to the business and its actors is developed in section 6, together with the issue of training and re/upskilling.

4. GUARANTEE THE SAFE USE OF AI

Certification/approval: Safety demonstrations need to include considerations for "learning assurance", and provide confidence that the result of the end-to-end chain of software development is safe. Reproducibility will be a major topic, particularly in the context of incident and accident investigation. This action area, including safety culture, just culture, liability and licensing-like certification aspects, is further developed in section 7.

5. MASTER AI TO REMAIN CYBER RESILIENT

Cyber-resilience: A key challenge is how best to exploit AI to increase the cyber resilience of aviation/ATM systems, as well as how to identify and address the new vulnerabilities of aviation/ATM in an AI environment. This action area is further developed in section 8.

6. BUILD UP AN INCLUSIVE AI AVIATION/ATM PARTNERSHIP

Partnerships: Aviation/ATM has for decades formed a highly specialised world attracting highly skilled experts. However, the advent of transformative technologies such as AI poses its own risk in terms of skills: there is a significant risk that AI talents could be attracted to other sectors. This action area is further developed in section 9.



4. FOSTER DATA SHARING FOR AI

Taking data-driven decisions and acting efficiently based on analysis, simulation and predictive models are the foundations of industrialised AI solutions. In order to allow provision for future AI/machine learning aviation/ATM application developments, it is crucial to give as broad as possible a scope to the aviation data.

Although the group was able to identify a few counter-examples (e.g. AIRBUS SKYWISE), the situation is still very much that each stakeholder needs to develop its own AI-based solutions on its own data. Most ATM stakeholders are by the nature of the industry successfully cooperating on data, nevertheless a number are still reluctant to share data. To maximise the benefits of AI/machine learning, there

needs to be access to the largest possible data sets, as well as to a variety of additional data outside the strict remit of a given business. As a community¹³, aviation/ATM could facilitate access to third-party data in order to improve the quality of AI-based services, reduce duplication and dispersion of effort, and consequently enhance business value for all stakeholders.

Sharing data for AI goes beyond the simple data sharing principles. It shall ensure that the access to the data needed in terms of quantity and quality is suitable for the development of safe and secure AI-based solutions and that industrial trade secret can be guaranteed. Thus it should include the following elements:

¹³ Community refers to all parties who have agreed and are respecting the data governance of the federated AI-infrastructure with the aim to facilitate the development of AI products for aviation / ATM.

1. DATA GOVERNANCE

A clear data governance among all will ensure that the community is collecting, storing, and using data appropriately to create shared value and European leadership in the field. A data governance approach for the aviation industry will clarify the right to use industry data for a set of applications in line with the associated data policy (e.g. data set anonymisation) to protect trade secrets, avoid conflict of interest, address safety concerns and encourage data sharing.

Such governance will not affect or limit the development of competitive products, but it will help guarantee that aviation/ATM data can be exchanged in a business driven, fair, safe and secure way. It should also ensure that data flows seamlessly and securely between organisations, functions and users. This has already been successfully demonstrated in the Skywise programme where airlines and possibly other parties under strict governance rules are invited to share subsets of data if they want to get access to the broader range of data. Another well-known example is the NM B2B web services which shares huge volumes of data with a broad community.

Data access rights should respect the following principles: a control over stored and processed data, and decision on who is permitted to have access to data. To ensure each stakeholder has access to that data, industry should collaborate around controlled sharing-enabled data platforms that place aircraft manufacturers, aircraft operators, ATM system manufacturers, ANSPs, airports and other stakeholders (and the third parties that may support them) on a level playing-field with their own businesses.

2. DATA QUALITY AND DATA MANAGEMENT STANDARD FOR AI

Defining and implementing standards for data handling, data structures, data elements, metadata and data quality will facilitate integration and utilisation in multiple applications and analytics. Such standards should support data integrity and quality checks.

A figure of merit of the data quality should be introduced, to clarify who is responsible for what during the data production, dissemination and storage and who is controlling whom and who is liable for what along the entire data cycle.

Open data emergence can favour competition and allow easy access to information. Some standardisation initiatives from the industry or industrial working groups data quality frameworks (e.g. Safecloud.eu project; ACI Europe data standard; EUROCAE, Skywise ontology) should be considered and be complemented to fully address data standards for AI applications.

3. DATA COLLECTION

In the frame of machine learning development and to allow an easy use for future applications that cannot yet be imagined, it is paramount to collect, store and make available as many data as possible. Anonymisation will be key to unlock data assessed as critical. We need to collect and store all operational data in a continuous manner; and we need variety of data in quality and diversity (either simulated or historical data) to reflect all kind of events and situations occurring in real life. The following table lists some of the key data generated by the aviation/ATM stakeholders that have the potential to generate value if federated:

Data producers	Candidate data
Aviation Met Service providers	Local, regional and global met info: MET observations (METARS, weather radar, satellite weather radar) Aviation MET forecasts (TAFs, World Area Forecast Services, SIGMETs, tropical cyclone advisories, Space weather advisories, European high resolution forecasts of Icing/Turbulence/Convection)
ANSP Civil and Military (General Air Traffic and Operational Air Traffic)	Capacity Regulations Sector configuration Traffic information (e.g. Arrival and Departure Manager data) Datalink messages Airspace structures Surveillance data CNS monitoring data ATCO working position tooling Flight Data Processing system data En-route charges Voice recording

4. Foster data sharing for AI

Data producers	Candidate data
Airports	Departure and arrival time (prediction and actual) Runway in use and taxi time Turnaround and CDM when available Gate assignment Surface surveillance Waiting lines and passenger behaviour inside the airport Luggage processing data Charges Curfew, noise and other operating restrictions
Airlines	Flight commercial schedule IATA-ICAO flight number matching matrix Flight priorities, flight operations data (flight reports, DAR/QAR) Passenger and cargo flows, load factors Delays, cancellations and their causes Aircraft swaps Crew duty rosters Aircraft in-service patterns (in-service configurations, in-service data, etc...)
Aircraft manufacturers	Per design Performance models Technical documentation Estimated configuration (service bulletin, STC, AD) Fleet lifecycle, future plans
ATC manufacturers	ATC systems' technical and performance logs
UTM / U-space Providers (USP) (ATM integration view)	Flight trajectories, traffic on routes / air-taxi vertiports, spatial data sets as per Infrastructure for Spatial Information in the European Community (INSPIRE) Directive and drone-permitted enrichments
Counter-UAV	Surveillance of UAV intrusion in critical areas, detecting and alarming abnormal behaviour.

Table 2: Some of the key data to be federated



5. FEDERATE AN AVIATION/ATM AI-SPECIFIC INFRASTRUCTURE

A future AI infrastructure would need to be established to enable data storage capability, data preparation and facilitate access to computing power.

A FEDERATED AI-INFRASTRUCTURE

Ideally one unique European AI infrastructure for the aviation/ATM community hosting and providing access to data and a data preparation environment to all aviation/ATM European AI actors could bring benefits of scale. However, multiple aviation stakeholders are concurrently embarking on sharable data/AI infrastructures, named as data lakes (e.g. AirSense, DataBeacon, OpenPrisme, Skywise, Topsky, Data4Safety, GAIA-X). Hence a practical good step forward would be to create a so-called federated aviation/

ATM AI-infrastructure connecting all data available on the multiple existing and to be developed data lakes for the benefit of the community.

DATA PREPARATION

Currently, data preparation for AI takes up to 60% of AI projects overall time duration. It includes: anonymization, annotation, quality control. Data are never fit for immediate use. In part, this is because the question is quality and format. Quality is 'fitness for purpose', and the purpose varies. When you say 'airline', is 'airline group', 'ticketing airline', 'buyer of fleet', 'operating airline', 'payer of en-route charges' intended, and so on. In such an example, the 'airline' field might be good enough for one purpose, but not for another.

5. Federate an aviation/ATM AI-specific infrastructure

Aviation has a lot of semi-structured data, with agreed codes for many dimensions (airports, airlines, aircraft types, delay reasons). However, in practice, the codes are used patchily and using local jargon. CODA has built a whole translation scheme to convert the dialects of 120 airlines into standard 'Airport Handling Manual' delay codes. Skywise has developed its own ontology. Likewise the ATM Information Reference Model¹⁴, which is used as a common reference for the development of various information and data models throughout ATM, is increasingly used.

It is also important that the data is validated and correct, otherwise AI will not recognize real patterns and ultimately will not be helpful. However there is no standard tool or emerging product on the market to fulfil data preparation needs. Moreover, current aviation/ATM data quality management standards have not been developed in the context of AI/machine learning. Hence, a more consistent and interoperable set of tools and rules should be established.

By bridging stakeholder data platforms in a federated approach, each community participant could benefit from each other's data preparation work. This could generate significant savings while increasing the size and quality of data sets for each stakeholder.

COMPUTATION POWER

AI demands a huge amount of computing power, and this computational power demand will increase over time. The AI infrastructure should facilitate easy access to computing power. The federated network of data lakes can be doubled with multiple federated data centers that can provide on-demand computational power. Such heterogeneous data repository solution could offer multiple options to all users.

TAKE AWAY

As a key enabler to AI-based solutions development, a federated data foundation and AI-infrastructure should be established respecting the following key principles:

- The establishment of a data governance to ensure that the community is collecting, storing and using data appropriately to create shared value,
- The sharing of data whilst respecting the following principles: control over stored and processed data and decision on who is permitted to have access to data,
- The collection by an ATM data community of all available operational data in the federated network of data lakes,
- The archiving of all real-time data to support the training phase of AI/machine learning developments,
- The use of open data exchange standards,
- The nomination of federators in charge of collecting and curating data,
- Data generated from collective data sets, being fed back to the collective data sets,
- The ATM Information Reference Model to be used as a baseline to build a common and unique aviation /ATM ontology, to ease data preparation process,
- An easy access to computing power through the AI-infrastructure

¹⁴ The AIRM captures terms and definitions from an agreed set of ICAO annexes and documents, as well as from global information exchange models such as the Aeronautical Information Exchange Model (AIXM), the Flight Information Exchange Model (FIXM), and the ICAO Meteorological Information Exchange Model (IWXXM): www.AIRM.aero



6. DEVELOP A NEW JOINT HUMAN MACHINE SYSTEM, SKILLS AND TRAINING

AI ASSISTANT

In the foreseeable future, AI enabled applications look set to become a valuable aid to all aviation/ATM actors. For ATC, it will substantially alleviate controller workload, proposing the best possible options to the controller (flows, sequences, safety nets, etc.) while solving complex trajectory situations using machine-to-machine communication between airspace users. In such a hybrid ecosystem, the purpose is not to take the human operator out of the process, but rather to combine the best of both computational methods

and human intelligence. This will result in increasingly collaborative service provision.

AI will also help airlines, ANSPs and airport managers take strategic decisions in a range of areas such as fleet management, infrastructure monitoring, sectorisation, staff planning, and so on. AI can also offer regulators new safety and security indicators that support the (early) detection and predictions of new risks. In summary, AI can improve human performance, assisting people in areas where the capabilities of AI far outstrip those of human users.

6. Develop a new Joint Human Machine System, skills and training

A JOINT HUMAN-AI SYSTEM WILL FAR OUTPERFORM EITHER ACTOR OPERATING IN ISOLATION.

However, while the introduction of new technology aims to improve operational performance, increasing complexity may also create its own problems, making it harder for human users to understand the reason for a particular AI action. If not well managed, the introduction of AI in ATM will add complexity to an already complex system.

Human Factors, when already applied from the design phase, can help reduce complexity and ensure an effective rapport between the human operator and the AI tool.

Hence, in order to manage and reduce this new type of complexity, the operator needs some degree of 'explainability'. In particular, the operator needs to understand how AI works and 'reasons', what exactly it is doing, what it can do right – but also what it could do wrong. Care also has to be taken that the AI system is not misinterpreted as having the capacity to understand and feel in a human sense, as this could potentially affect team work. More research is needed on explainable AI components.

The operator needs to develop trust in AI to assist. Furthermore, as with any aviation/ATM system, the operator needs to retain certain core skills to take back control safely in case she/he judges the AI analysis to be erroneous or inadvisable, or in case of temporary AI unavailability or failure. There will need to be appropriate fall-back modes for human intervention, although these could be at a significant cost to performance, resulting in a high environmental impact or considerable delay.

Hence, a new human-machine partnership between the human and AI needs to be established. The Joint Human

Machine System (JHMS) philosophy leads to human and machine being considered as components of a system that has been designed to ensure that AI enhances, not supersedes, human capabilities. In such a system, automation and people do not compete but have to coordinate as a joint system, a single team. To achieve this, the involvement of operational staff in early stages of system development will be critical, as this provides a guarantee that the system will comply with all user's requirements. This will increase its usability and acceptability as a useful tool instead of as a competitor. In the aviation/ATM environment, where team work is a key component of success, the effects of these systems on end users should be assessed and monitored during their initial introduction, and potential changes to human resource management identified as appropriate.

Hence, users need to grasp enough of the AI-based system and build trust so that they are able to make it function in a high-performance manner and in a complex environment.

HIGHER LEVELS OF AI DECISION-MAKING

In the current AI/machine learning applications, the role of the human does not change significantly. However, when AI is capable of supporting higher levels of automation/autonomy or more advanced decision-making/reasoning tasks (see Figure 10), it will be essential to assess and redefine the tasks of the human within the JHMS to ensure meaningful interactions and appropriate oversight and control. In particular when considering full autonomous systems, we may reach a paradigm shift where the human may no longer be able to safely recover AI failures. Therefore, these advanced AI-based solutions would require increased system robustness or adapted contingency procedures, as is the case for any safety-critical system today.

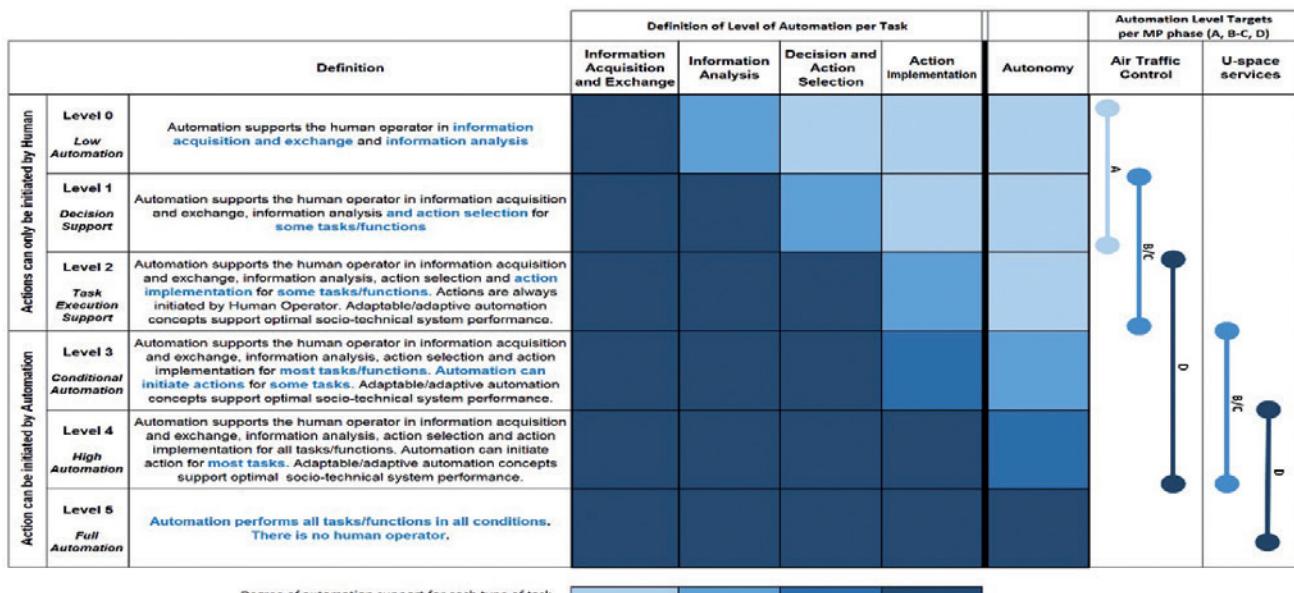


Figure 10: Levels of automation foreseen in the European ATM Master Plan

Such advanced AI capabilities have not yet been deployed in aviation/ATM, but would create a new interaction model with new reasoning/decision making processes which differ from human intelligence. This naturally would necessitate new models of interaction as all existing models are based on human-related ones.

Additionally, the degree of delegation could vary depending notably on the type of AI used and the level of customisation to the user's performance. Hence, while the AI system should enhance the performance of the human, they could if customised to the operator lead to a variable, non-systematic and non-deterministic involvement of the human in decision-making. Therefore, a prescriptive involvement of the human may not be appropriate in all circumstances.

With more advanced or customised AI-based tools, notably those leading to problem-solving, decision-making or reasoning, new Joint Human Machine System models will need to be developed. Moreover, further research is needed on AI in the context of high levels of automation and/or high levels of reasoning and decision-making.

TASK EVOLUTION

The introduction of AI will unquestionably impact the way work is performed in the future. Some tasks will be fully automated, others will be modified, and entirely new tasks and roles will be introduced. Dialogue with social partners and learning from the implementation of disruptive technology in other sectors will be required to balance the societal impact against such aspects as safety, environmental impact and capacity.

The European Commission is already assessing the impact of automation/digitalisation/AI on work as part of a study on social issues and working conditions of ATCOs and Air Traffic Safety Electronics Personnel (ATSEP). Other European projects are also investigating how humans are impacted by ever-increasing levels of automation, and how AI-enabled applications can interact with pilots and strengthen flight crew performance. However, it is clear that there is still much work to be done before we are fully confident about the introduction of AI in the cockpit, control centres or towers.

TAKE AWAY

More research is needed on human factors to establish an efficient, safe and secure Joint Human Machine System where AI-based solutions can be identified to the end user; this should help enhance the human capability to analyse the situation and retain core skills. This includes:

- **Developing AI-human interaction models** to support the design phase of the most advanced AI applications (i.e. reasoning, resolution, decision-making etc.)
- **Developing verification techniques to assess user trust in the new AI-based system behaviour** at any stage of the lifecycle
- **Assessing ethical, legal, societal impacts, levels of trust, new tasks, roles and responsibilities of the end user in an AI-based JHMS**
- **Developing explainable AI components** to ensure its acceptability including certification
- **Assessing human factors performance when AI is being used for higher levels of automation/autonomy or for more advanced decision/reasoning tasks in the context of safety-critical operations.** Moreover, in the context of the aviation/ATM safety framework, the limit between AI enhancement and AI augmentation should be defined
- **Exploring AI in automation research** to assess whether and in what ways AI can be used in a highly automated and safety-critical environment to deliver substantial and verifiable performance benefits – while at the same time fully addressing safety concerns and human's skills,
- **AI/ML developments** should be conducted under the following essential principles:
 - Building multidisciplinary design teams including operational end users, aviation specialists, human factors specialist, human specialist (physiological and psychological / cognitive aspects), AI and data analytics specialists, etc....
 - Selecting appropriate conditions for AI-based application evaluation: day-to-day operations and non-nominal situations

DEVELOP AN AI CULTURE THROUGH TRAINING/RE/UPSKILLING AND CHANGE MANAGEMENT

Most sectors transitioning to a digitalised workplace and in particular developing AI-based solutions are faced with the same issue – a shortage of the required AI skills among existing staff, and the high costs of recruiting staff with AI expertise. Aviation/ATM is no different in this regard. Furthermore, AI has not formed part of the training of aviation engineers so far. Hence, aviation/ATM expertise in AI is still limited, and few connections have been built with the academic world of AI.

To tackle this gap, a workforce that includes aviation data scientists and analysts should emerge together with expertise in data modeling, data engineering and related competencies. These profiles will be supplied by a limited number of experienced hires coupled with an extensive effort to train existing staff with precursor skills in the business: existing staff in our industry are often highly numerate as well as having a strong business understanding, both of which are good departing points for developing an understanding of data science.

Online training courses on AI do exist, but they tend to be diverse and cover too many topics, with a clear lack of guidance on where to start. In any case, AI technology is developing rapidly, requiring constant adaptation and making many general courses swiftly redundant. Finally, to be successful in AI development, business knowledge is fundamental.

The EAAI HLG considers that upskilling and on-the-job aviation/ATM AI-related training is necessary as well as change management.

However, such training courses will very much depend on the function of the staff. In-depth training will apply primarily to industries developing AI applications. Regulators, who will play an essential role in defining the “still to be defined” certification/approval criteria, should also follow specific training addressing both the technical and operational specificities of AI, and should be acquainted with the regulatory testing framework proposed in a number of European Digital Innovation Hubs.

It will be essential to train end users like ATCOs/supervisors, airport operators and ATM flow managers on such matters as AI awareness, trust in AI and to understand its expected behaviors under normal and rare abnormal conditions. However, in a highly automated environment and/or future AI-based environment in which controllers could lose their current skills, maintaining human abilities to guarantee safe and secure management of extremely rare but safety critical events will require new type of operational training and reskilling programmes.

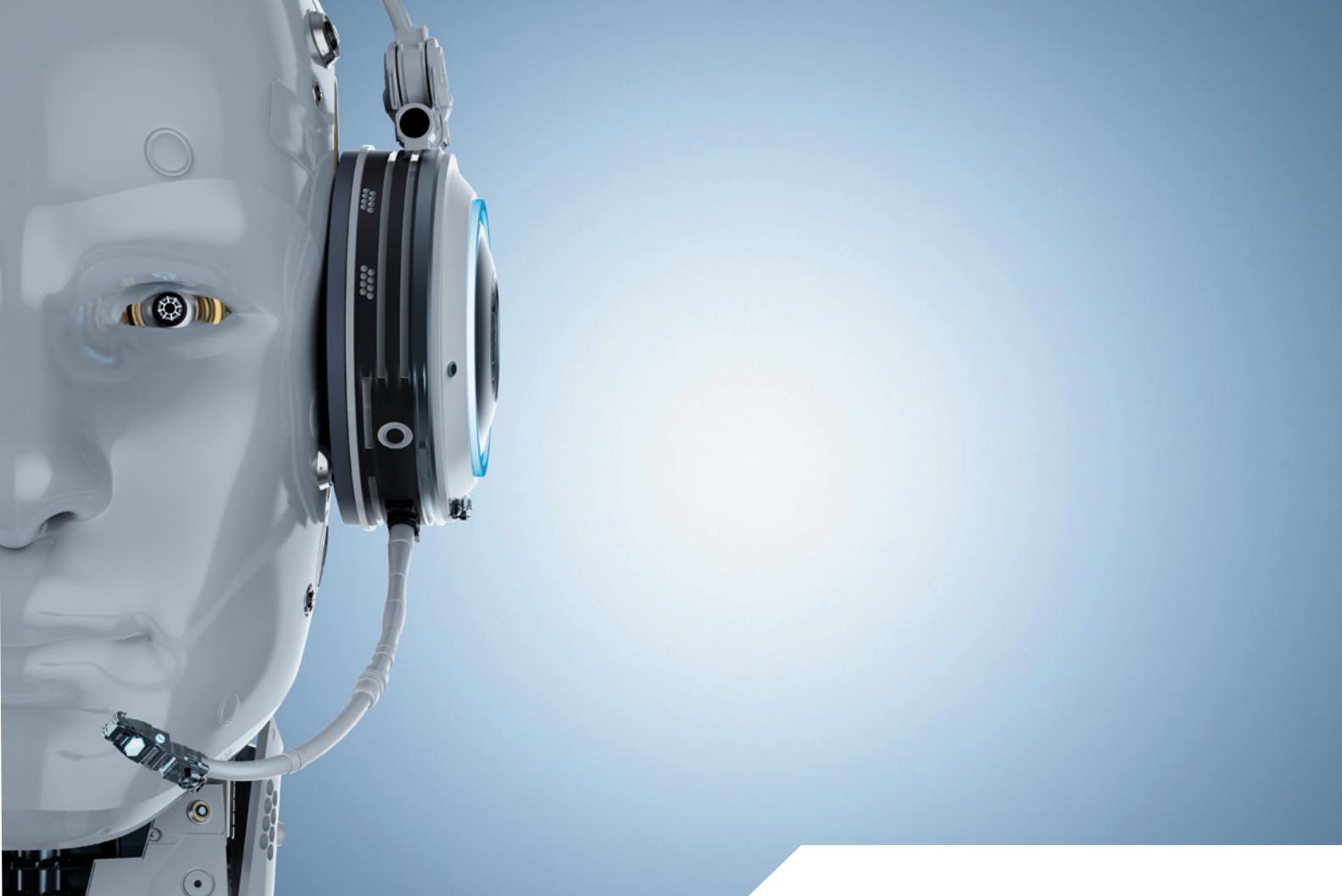
Deployment of AI will require significant efforts in change management and training to address the full range of needs from users to developers across the aviation/ATM sector.

Altogether, to embrace fully AI, we need to nurture an “AI culture” in aviation/ATM through training, (re/up) skilling programmes and change management. The purpose of creating an AI culture is to ensure that developers can master data exploitation, appropriate cross-functional collaboration is established, and learning from realistic use cases is encouraged, as this will facilitate agile, safe and secure AI development. Moreover, an AI culture should aim at demystifying the whole topic of AI, while establishing the required level of trust needed to facilitate acceptance of AI by human operators.

TAKE AWAY

In line with EC AI HLEG recommendations, an **AI culture should be developed**. It should rely on:

- **A knowledge based tool box** to help:
 - Identify AI business-specific opportunities
 - Plan for resources (skills, training, computing capabilities, data management)
- **Specific Aviation/ATM training, reskilling/upskilling programs** and change management including:
 - customised training suitable to introduce staff to AI (e.g. AI developers, AI users) and at all levels in the organisation (executive, managers, domain specialists, data scientists)
 - Dedicated aviation/ATM – AI training programmes, covering AI-based systems, the new threats they bring, and failure mitigation measures
 - Regular training courses and technology watch to tackle the rapid evolution of AI technology (in particular cybersecurity aspects)
- **European AI aviation/ATM master classes**, sharing lessons learned and best practices
- **Awareness & demystification campaigns**.



7. GUARANTEE THE SAFE USE OF AI

Aviation is seen by other industries as a 'High Reliability Organisation' (HRO). Safety, in the levels of aviation, is something of an 'emergent property', built on the professionalism within the industry, and decades of evolving systems, best practices and procedures. Safety culture has also impacted aviation, yielding tangible safety benefits, and has become commonplace, reflected in the Safety Management Systems of many organisations. With the introduction of AI, it is essential to maintain if not further improve the current levels of safety.

This has triggered new attention in the aviation community. Hence AI development and deployment has become a new area of special attention for IATA. One of IATA's Safety Strategy key areas is to "Identify and Address Emerging

Safety Issues". Indeed, a multitude of complex questions need to be addressed in the **certification/approval of AI-based solutions**. They relate to many factors: the level of automation/autonomy, software assurance levels, liability, human factors, trust, ethics, cybersecurity, training, licensing, data quality management as well as verification/validation processes and tools and reproducibility.

As explained below, **safety-related AI-based aviation/ATM applications relying on a thorough safety assessment should be operational in the coming months**. Moreover, AI has also the potential to improve safety. Initial investigations are calling for its further exploitation, notably in safety intelligence tools.

7.1. AI CAN IMPROVE SAFETY

Controlling and improving Aviation safety has historically been achieved using both comprehensive incidents / accidents analyses to stop them occurring as well as safety assessments and safety cases documenting and recording the safety of aviation services or systems. They both rely on service experience, i.e. data from previous operational use. Proof of past safety achievements has turned out to be difficult since suitable baseline did not always exist or sufficient historical data was not available. Hence quite often, safety evidence has been based on expert judgements. Digitalisation and AI, however, open up new possibilities for aviation safety, as huge amounts of data can now be processed in order to identify unknown incident patterns and early detection of precursors ('weak signals'), including previously hard-to-analyse data such as informal written reports. In addition, digitalisation enables us to virtually recreate such events, and so improve the definition of preventative actions such as retraining, improved supervision, etc. It will also help improve the design of future systems by modeling their behaviours with AI based on historical data.

A number of projects have already started to explore the benefits of AI for safety. NATS has developed machine learning algorithms to help predict the likelihood of potential safety events – such as aircraft level busts, or airspace infringements – in London Terminal Control operation. Such data are used as a weekly forecast at the Swanwick Centre to help avoid potential issues days before they might occur. The Safecloud (Data-driven research addressing aviation safety intelligence) H2020 project also aims at using AI to enable safety intelligence services.

Another potential application of AI is in the Traffic Advisory algorithms of the Airborne Collision Avoidance System (ACAS). Research results have demonstrated that an artificial neural network drastically reduces the size of the current decision logic, whilst surpassing the performance of the former TCAS systems.

7.2. MORE R&D IS NEEDED ON AI CERTIFICATION

While the safety assessment methodology for ATM/ANS systems and services was originally based on well-established safety procedures - namely ARP4754A (Guidelines for the system development) and ARP4761 (Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment) - the approach towards the system development, safety assessment, and design assurance of ATM/ANS systems and services and aircraft/avionics follow different standards as means to comply with regulations.

Considering the new entrants to the airspace, the U-space regulatory framework is currently being developed as well as the future safety governance systems that must ensure the safe integration of drones and personal air vehicles into the aviation system. It is likely that the safe and flexible integration of U-space services in a real environment will rely extensively on AI.

Adaptive or intelligent systems would need to be able to provide the level of safety required by the system design. Hence, the software assurance process would need to implement and verify the system-level requirements. While, the fundamentals of the safety assurance process will remain valid, the verification and validation approach should need some adaptations in order to overcome the challenges to the safety assurance of safety critical autonomous systems. This is explained below.

■ AVIONICS SYSTEMS CERTIFICATION

The goal of certification of an avionics system is to provide confidence that the system is correctly and safely performing its intended function. To reach a sufficient confidence, the current certification process is based on structured industrial development lifecycle ensuring a full downstream and upstream traceability and the collection of deterministic arguments built at each phase of this lifecycle. Since AI, and in particular Machine Learning, is relying on the capacity of the machine to learn by itself in an automated way, there is definitely a need for modifications to be brought to the certification approach.

■ ATM/ANS SAFETY APPROVAL

ATM/ANS systems are not certified in the same way as aircraft systems. Nevertheless, any change introduced is subject to it being possible to demonstrate that the change to the functional system has been specified, designed, implemented and validated to be safe. The acceptability criteria ("to be safe") is called the safety criteria in the EU regulation addressing safety assessment of ATM/ANS changes ((EU) No 2017/373). The safety criteria are determined based on the scope of the change, and will therefore capture the nature of the AI-based systems/services/applications to be deployed. In a similar way to new ATM/ANS concepts (e.g. SESAR), the broader safety approach (success and failure)¹⁵ to safety assessment should be used to assess any AI-based change considering normal, abnormal and faulty conditions. Furthermore, a safety/human performance integration process is arguably essential in order to capture and analyse the new role of the human operator, and his/her associated dynamic capability to monitor/supervise/act as the AI-system learns more and more patterns during operation. Risk modelling will also be essential to re-evaluate the strength of the different ATM/ANS safety barriers (strategic, tactical and collision avoidance) that are impacted by AI-based systems/services/applications.

¹⁵ SESAR Safety Reference Material (SRM) : " D4.0.060 SESAR Safety Reference Material Ed 00.04.01" dated 14 December 2018

The main concern to overcome in the coming years for the different actors (ops, safety, etc.) will be to ensure the reliable behavior of the ATM/ANS functional system with AI. AI reasoning can be very difficult to understand, and difficult to validate. Even if AI were only to support decision making, its potential failures must be appropriately mitigated in the design phase. However, in terms of determinism, there is really no difference with the situation today. Two different controllers can have different strategies for solving the same conflict. AI based solutions can thus also be certified. ACAS X is one of such examples.

Another concern is that AI reasoning can be very difficult to understand and demonstrate for a human; explainable machine learning is an active research area, but far from mature. As identified in the context of automation, humans need to understand the decisions and the reasoning behind AI behaviours. The problem of explanation is however further exacerbated by the use of AI in the context of a complex system where performances are the results of interactions between different components of which AI could be a part.

There is also a need to develop new processes, procedures and tools to check algorithms and especially trained/implemented AI 'solutions' – on-premise or in the cloud - to ascertain that they are trained, integrated and maintained properly, and deliver the intended results without any unintended 'side effects'. This includes but is not limited to:

- Procedures to test and check that AI technics (neural networks, etc.) are delivering the right results and are not being tampered with

- Procedures and tools to safeguard machine learning algorithms in their lifecycle ('make sure that they are not learning 'bad things'), unintentionally or as deliberate sabotage
- Procedures to estimate or measure the residual risk in the suggestions of an AI technic
- Procedures to test and check the interfaces to those AI technic
- Procedures to ensure that AI when implemented cannot create a safety impact or a business risk.

■ EUROCAE/SAE STANDARDIZATION INITIATIVE

European aviation industry stakeholders and SAE have recently launched EUROCAE WG 114/SAE G34 group on artificial intelligence. Its objective is to adapt the current certification/approval frameworks to AI-based applications. It addresses both on-board certified systems, and ATM/ANS AI-based applications/services.

The future process for certification/approval of AI-based products, as currently discussed in this group, could include features like learning assurance, formal methods, testing, explanation, licensing, in-service experience, and online learning assurance. Depending on the product to be certified/approved, on the requirements coming from the trustworthiness analysis, on the safety assessment, and on the certification/approval strategy chosen by the applicant, only a subset of these activities could be required, and the depth of demonstration could also be adapted for each activity as depicted in Figure 11 below.

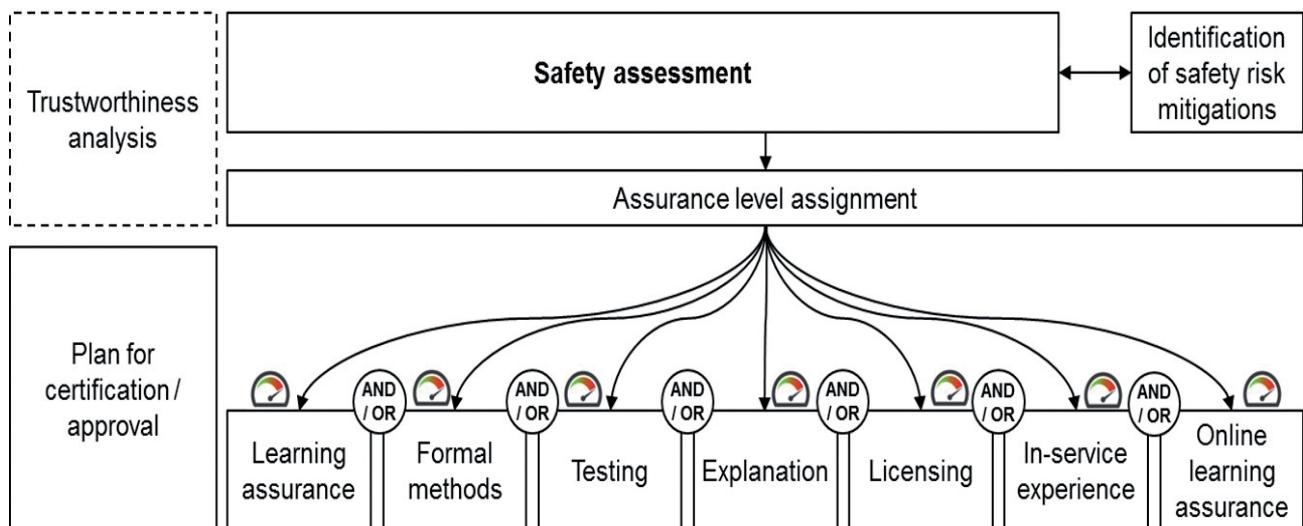


Figure 11: A proposal for the future process for AI-based products

7.3. SAFETY CULTURE, JUST CULTURE AND LIABILITY

The increasing use of AI and other emerging digital technologies has created tremendous opportunities for safety improvement, but also assurance challenges. The levels of connectivity across systems as well as the sharing of responsibilities for safety between the ground and the air and between technical and human elements of the system, with a potential shifting of more safety responsibilities to suppliers, call for safety assurance techniques capable of addressing the increasingly collaborative nature of service provision. Faster, more agile development is likely to put pressure on regulatory systems and validation/verification/certification processes. A safety management system only works if there is a strong safety culture to bring it to life, especially in a highly competitive business environment. With increasing reliance on external software providers, a strong indication of the safety commitment of third-party suppliers will be required. Safety culture would need to be spread across a broader community to the extent that safety data and information are willingly shared and analysed, which will lead to better safety intelligence and justifiable, proportionate and tailored safety-related decisions. Even if the interplay of various factors that either separately or jointly have led to a serious incident or accident could become more complex with advanced capabilities incorporating AI algorithms, the concept of "Just Culture"¹⁶ as an essential element of a broader safety culture and a robust safety management system should apply to software suppliers to encourage and share best practices that enhance ATM/aviation safety.

Best practices in designing, analysing and validating the development of AI-based algorithms, in combination with robust safety management practices, cannot completely exclude the possibility of damage resulting from the operation of these technologies. If this happens, victims will seek compensation, typically on the basis of liability regimes. In accordance with Commission Implementing Regulation (EU) 2017/373¹⁷, air navigation services, air traffic flow management providers, the Network Manager and in the future, ATM Data Service Providers shall have in place arrangements to cover liabilities through insurance related to the execution of their tasks. As many technical solutions, including software development, are not built in-house, agreements that they conclude to that effect should specify

the allocation of liability between them. However, and in common with broader approaches to safety assessment¹⁸ considering human error not as a cause but a symptom, and the ATM system as a whole rather than solely focusing on the human contribution to incident/accident, the liability regimes for AI and, more generally, digital technologies¹⁹, should take into account the potential for AI-based software to improve still further the safety level of aviation. Certification standards for AI-based systems when available will be the ground for addressing the AI-enabled systems' liability concerns.

7.4. LICENSING-LIKE CERTIFICATION

In order to provide an Air Traffic Control (ATC) service, an individual must hold an ATCO license, as well as the ratings and rating endorsements relevant to any specialist tasks. This requires successful completion of initial training at an initial training organisation, followed by unit training under supervision. Similarly, pilot licences and rating are official authorisations to fly. Both are based on demonstrating knowledge and skill through 100s of hours of training and evaluation, including using simulation training devices. With respect to AI-based software products, a key phase is the so-called 'training' phase, after which a convergence of the software function is reached, i.e. it should be possible to predict outputs for a new, previously unseen set of inputs.

Considering the objective of this training phase for the software, a potential approach could be to consider whether similar training techniques to those applied to license ATCOs and pilots could be used to address safety and certification considerations. A system encapsulation AI-based software might, for example, be required to go for "hundreds of thousands of simulated hours, and thousands of real hours, encountering thousands or millions of faults and contingencies, demonstrating competency far beyond what any human could possibly show in a lifetime"²⁰. Over time, whereas pilots and ATCOs at the sharp end of the ATM/aviation System are quite agile in reliably and quickly adapting to a changing environment, there should be a need to quickly re-test a changed system against the full range of desired outputs in both nominal and abnormal conditions before bringing it back into operation.

16 Just culture is defined as a culture in which frontline operators and others are not punished for actions, omissions or decisions taken by them that are commensurate with their experience and training; only gross negligence, deliberate violations and destructive acts are not tolerated.

17 COMMISSION IMPLEMENTING REGULATION (EU) 2017/373 of 1 March 2017 laying down common requirements for providers of air traffic management/air navigation services and other air traffic management network functions and their oversight, repealing Regulation (EC) No 482/2008, Implementing Regulations (EU) No 1034/2011, (EU) No 1035/2011 and (EU) 2016/1377 and amending Regulation (EU) No 677/2011.

18 Safety-I to Safety-II: A White Paper, EUROCONTROL, 2013.

19 Liability for Artificial Intelligence and other emerging digital technologies, Report from the Expert Group on Liability and New Technologies – New Technologies Formation, European Union, 2019.

20 Certification Considerations for Adaptive Systems, NASA, 2015.

Such an approach, leading to a proven record of performance accomplishment rather than an implied guarantee of perfection, could also be considered when defining the liability regime.

In summary, the current ATM/ANS safety assessment framework should remain fully appropriate. Nevertheless new risks and mitigations associated with the development of AI-based solutions need to be understood, and procedures developed to address their full lifecycle.

MUAC's trajectory prediction tool is already operational and is paving the path for the early adoption of AI in ATM safety-

related operations. It demonstrates that for applications that meet specific characteristics (appropriateness of statistical methods) and that are safety-relevant rather than safety-critical, the existing safety assessment framework can be applied if done carefully. Key success factors are structured and continuous validation processes and proper failure mode handling.

Over time, as more experience with AI and associated methodologies is acquired, and safety regulations are updated, AI may gradually find its way in more safety-critical applications.

TAKE-AWAY

AI APPLICATIONS SHOULD BE FURTHER CONSIDERED IN THE AREA OF SAFETY

R&I should be primarily focus on Safety-Critical Operations to 1) further explore AI potential in safety-critical operations, and 2) develop new methodologies for the validation and certification of advanced AI applications that will ensure their transparency, robustness and stability under all conditions and the development of Safety Intelligence Tools

Validation and standards:

- **Develop specific AI-based guidelines** capturing and further developing safety procedures for safety and non-safety-critical AI-based solutions covering the full aviation/ATM operational scope.
- **Adapt ATM/ANS safety cases to AI-based solution specificities.** This would require:
 - Reconciling certification with the need to frequently update AI algorithms
 - Creating the necessary processes, procedures and tools to check algorithms and especially trained/implemented AI 'solutions' – on premise or in the cloud – to ascertain

that they are trained, integrated and maintained properly, and deliver the intended results without unintended side effects,

- Filling in the expertise gap between designers/developers and regulators when it comes to adopting AI in an aviation/ATM context
- Reviewing and adapting the current approach to produce an accurate and trustworthy safety case
- Adopting a verification/validation approach based on probabilistic analysis (convergence to a solution within a given deadline)
- Considering the need for, and the extent of, adapting **the liability regimes for companies providing AI software**, in particular if performing high-level decision-making functions normally performed by human ATCOs/pilots
- Considering the extent to which the **ATCO/pilot licensing logic could be extended to the validation/certification of software encapsulating AI-based algorithms** (in particular those related to machine learning).



ARTIFICIAL INTELLIGENCE

8. MASTER AI TO REMAIN CYBER RESILIENT

Cyber-security attacks can affect finance, capacity, delays, regulatory compliance, etc., whether or not there may be a safety impact.

The aviation/ATM sector is developing its own cybersecurity framework taking into account the global nature of ATM and the interconnections of aviation stakeholders in a commonly shared system of systems.

Most cyberattacks target the weakest link in a given organisation and, in the case of aviation/ATM, the weakest link in that ecosystem, as depicted in Figure 12.

The cybersecurity framework should be revisited to ensure that new cybersecurity risks originating in AI are better understood, and appropriately managed. Moreover the benefits from the exploitation of AI to increase cyber-

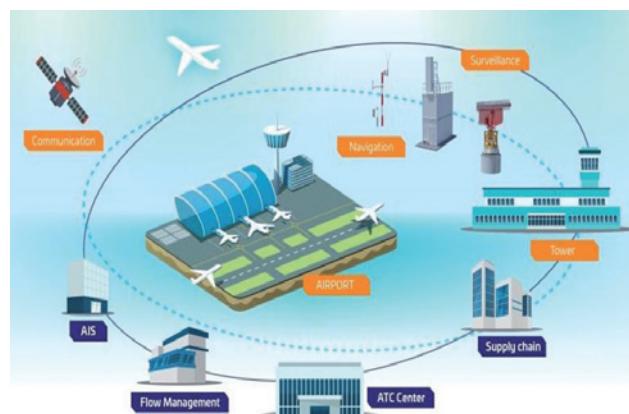


Figure 12: Aviation/ATM ecosystem

resilience, and the new risks introduced by AI when used in cyber-attacks should be investigated as further analysed in the following sections.

8.1. IMPROVE CYBER RESILIENCE WITH AI

Cybersecurity threats, vulnerabilities and indicators of compromise (e.g. malicious IP addresses, URLs, malware signatures) are established from volumes of information available from thousands of web pages and extracted from various sources. Many have no direct link to aviation/ATM, and among them there is a significant amount of fake or irrelevant information.

The data processing, analysis and detection of these data still depend very much on human operators. AI, with its ability to manage and analyse large sets of data based on sophisticated algorithms, can deliver new or improved services in:

1. CYBER DETECTION AND CYBER INTELLIGENCE:

- Focus on relevant information
 - Avoiding missing relevant information per aviation stakeholder;
 - Avoiding wasting time processing irrelevant information;
 - Adapting searches to individual aviation stakeholders (there are very different priorities of cyber intelligence depending on the stakeholder, its operational, financial, geo-political contexts)
 - Enhanced cyber monitoring and detection in aviation.
- Detect and cope with intelligent adversaries through
 - Anomaly detection and attack detection
 - Intrusion detection (cyber and security) and provide rapid self-healing after intrusion of the systems
 - Ultimately predict cyberattacks (including intelligent, adaptive attacks), threats evolutions and automated cyber-defences.
- Isolate the attack and minimize its impacts
 - Neutralise or delay ongoing or developing attacks by applying intelligent, adaptive approaches.

2. SCARCE CYBER-THREAT ANALYST RESOURCES

- Classify diverse types of events in a Security Operation Center (SOC)
- Provide autonomous decision aid
- Identify pattern conception

- Support risk analysis
- Improve simulator capabilities, notably through more realistic threat scenarios.

3. DESIGN MORE CYBER-RESILIENT SYSTEMS THROUGH

- AI-based verification
- Auto generation of 'attack trees' for critical infrastructure and aviation systems of systems
- Identification of faulty, failing or misconfigured or compromised components of the system
- Adapting risk mitigations and security control to aviation's needs
- Linking weak signals and modelling suspicious interactions inside IoT or Air Traffic Operations system data flows
- Provision of new levels of automation for non-safety-related systems.

The ISO/IEC/IEEE 15288 lists up to 30 processes that can benefit from these AI opportunities.

However, to benefit from AI, European ATM cyber data should be collected and securely stored in a systematic, harmonised, processable and preferably decentralised way. Data sources and data integrity should be protected and preserved as an immediate action.

There is also a belief that all AI-based cyber-tools would have to be adapted to the specific aviation context. However, a number of them could directly be used with a minimal cost to the community. For this, an assessment by AI specialists and cyber-specialists on customisation requirements of cyber AI-based tools to the aviation/ATM environment would be needed. Common cyber AI-based tools should be agreed and deployed in all aviation/ATM SOCs in Europe. Moreover, all actors of the aviation/ATM chain from design to operation need to be increasingly aware and informed about how these tools could be used.

Non-safety-critical AI-based cybersecurity solutions can and should be advanced, validated and deployed immediately. They should also integrate the ethical dimension and contribute to the lawfulness aspects of trustworthiness. They can be also used for safety-critical AI-based solutions at a later stage.

8.2. RESPOND TO NEW AI THREATS

AI can also pose a significant threat to ATM in two ways: (1) via AI-specific vulnerabilities, and (2) by generating new attack vectors in the system. This can happen at three levels: during the creation of the dataset, during the learning phase, or during the inference phase.

Vulnerabilities of AI include:

- **Data poisoning:** It injects biased or false data or training data (independent from the model). This leads to the creation of a model that will not function according to the expected requirements.
- **Data leakage:** Training data are modified. Most such attacks are difficult to plan and to execute without being inside the AI factory, since attackers need to remain very discreet.
- **Adversarial inputs:** These could include adding invisible 'noise' for the human eye: these could be input into a trained network during its running time, and lead to an unexpected output that is very different from the one obtained from un-noisy data. This is due to the possible instability of the model.
- **AI model leakage:** All machine learning models are confidential. Model stealing is when a malicious user tries to duplicate the functionality of a private model. The output of the system then becomes predictable and can be used for malicious purposes.
- **Jitter-based attacks:** This consists in creating a data desynchronization. This way, false operations mask real ones. A solution may consist in data augmentation.
- **Physical attacks:** Fault injection, SCA. This kind of attack requires a physical operation near the AI system, either by using a laser, a light flash or any other electromagnetic disturbances close to the GPU card used to run the AI model. This kind of disturbance may lead to the injection of false data during the incident. Generally, such disruptions are not permanent, or if so, they manifest themselves as random perturbations on the output of the AI model.

AI can also help attackers create or improve known types of attacks. A few well-known examples are:

- **Targeting** the weakest link inside the (institutional, private) network
- **Spear phishing** where AI is used to simulate very convincing email exchanges
- **Voice (or even face/image) simulation** where AI can help identity usurpation.

Aviation/ATM actors need to understand these new vulnerabilities and threats introduced by AI/ML algorithms. In this respect, awareness campaigns on new AI threats in the cybersecurity are essential prerequisites.

Based on evidence, a majority of cybersecurity breaches are due to human actors inside an organisation. It is therefore of the utmost importance to include physical security data (e.g. personnel data access rights, manual manipulation) in cybersecurity AI/ML algorithms. Moreover, as a matter of urgency, aviation/ATM should increase further and in a systematic way the level of protection at organisational level and between aviation/ATM interconnected actors/systems and their protocols with AI and against AI attacks.

As a process with significant reach and potential impact on ATM/aviation operations, cybersecurity programs and the dataset used as a basis for analysis should be subject to regular oversight and governance.

An appropriate governance structure that suits the size and complexity of European aviation will ensure that the fundamental aspects of a cybersecurity program with high data quality are in place. Clearly-defined roles, policies and processes will enable organisation-safe, flexible, and swift decisions to be taken by authorised and trained decision makers.

TAKE-AWAY

AVIATION/ATM ACTORS SHOULD ACCELERATE THE UPTAKE OF AI IN CYBERSECURITY DOMAIN TO

- 1) increase aviation/ATM cyber-resilience,
- 2) respond to AI specific vulnerabilities and more sophisticated cybersecurity attacks

Through research and development actions:

- Customising and developing cyber intelligence services for aviation/ATM,
- Explore, customise and develop usage of novel technics based on machine learning cyber threat intelligence services for aviation/ATM.

Through deployment and operational actions:

- Using and deploying common mature AI-based agile cyber tools for aviation/ATM to cover the operational European aviation and ATM network needs (e.g. the European Aviation SOCs, threat intelligence centres),
- Secure collecting, secure storing, managing and maintaining cybersecurity data sets for Aviation/ATM AI-based developments in a systematic, harmonized, processable and decentralised way,
- Increase the cyber protection of all its data sources as an immediate action,

■ Assess the need to adapt an aviation/ATM cyber security governance and policy framework to adopt AI,

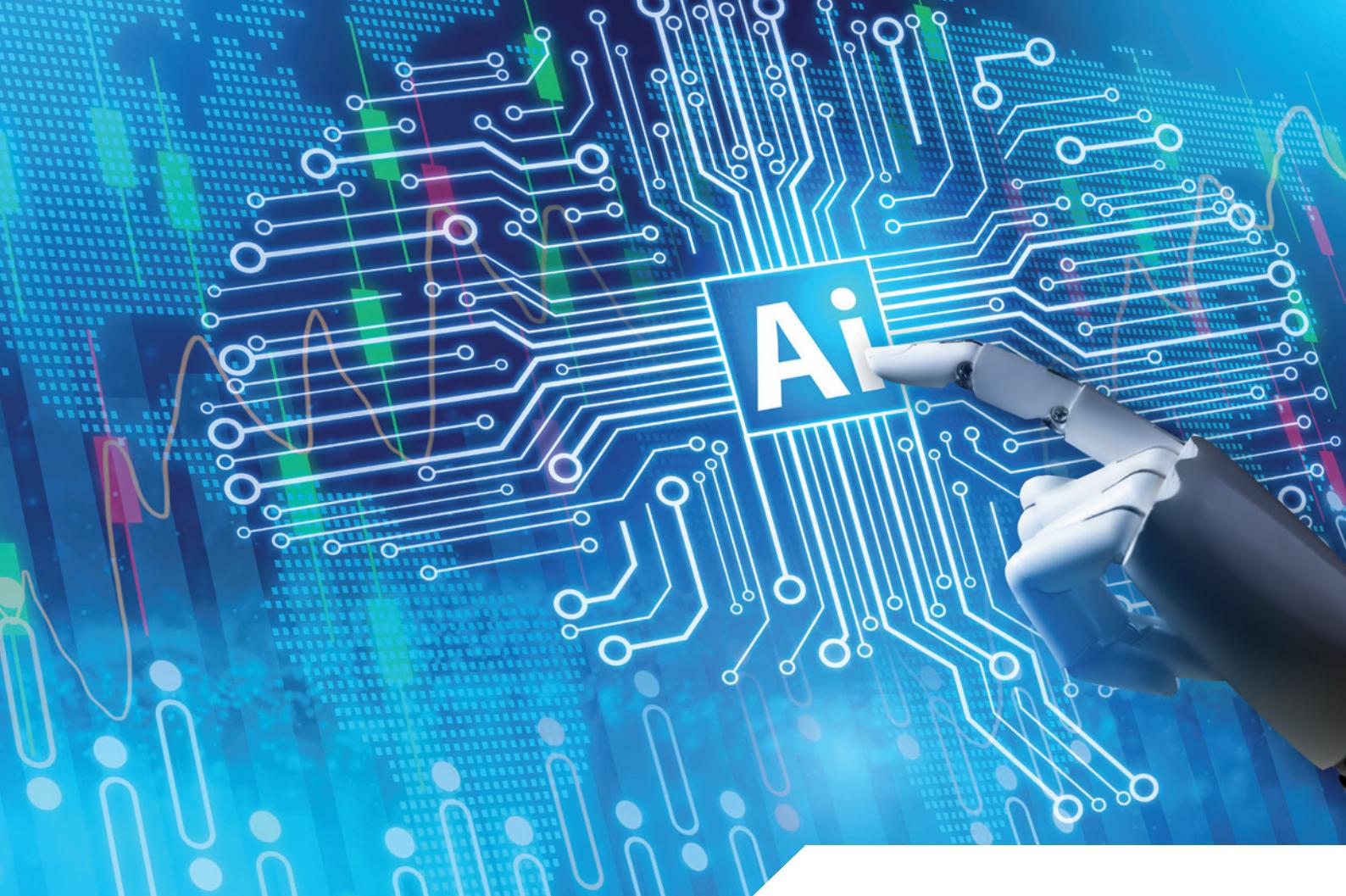
■ Include the cyber-dimension in the trustworthiness demonstration of AI-based applications for non-safety and safety-critical operations.

Through Training, awareness and communication actions:

■ Conduct awareness campaigns and develop training programmes (including simulation capabilities) regarding AI technics and associated cyber risks.

By applying essential principles:

- Relying on AI to compensate for the scarce cyber-threat analyst resources,
- Integrating AI into the design phase,
- Ensure that the scope of correlation of AI/ML algorithms for cybersecurity purpose is extended to cover physical security.



9. BUILD UP AN INCLUSIVE AI AVIATION/ATM PARTNERSHIP

Under "AI for aviation", the Digital European Sky blueprint²¹ recognises that tomorrow's aviation infrastructure will be more data-intensive. Thanks to the application of machine learning, deep learning and big data analytics, we will be able to design an ATM system that is smarter and safer by constantly analysing and learning from the ATM environment.

The EAAI HLG recommends that the uptake and scaling of AI systems in Europe be analysed and encouraged within the context of "enabling AI ecosystems" to gain a sufficiently granular understanding of the specific needs and challenges raised within the ecosystem. Sectoral-based

in-depth analysis to identify opportunities, challenges and the requirements to enable those opportunities is seen as a mandatory prerequisite. This FLY AI report represents an initial attempt in that direction.

In the medium term, the EC's High-level Expert Group on AI recommends the setting up of Sectoral Multi-Stakeholder Alliances (SMUHAs) for strategic sectors in Europe, enabling them to build their AI ecosystems with the relevant stakeholders. This approach mirrors that of Public Private Partnerships, which bring together industry, research and academia, the public sector, civil society and user-focused organisations, as well as policy-makers.

²¹ https://www.sesarju.eu/sites/default/files/documents/digital_european_sky_blueprint.pdf

The European AI research community comprises a number of smaller research centres and laboratories across Europe, each with its respective strengths ranging from specialised research and innovation domains up to large-scale and broad international regions. It is therefore urgent to strengthen the connection between the European Aviation/ATM with the AI community.

For example, AI4EU "A European AI On Demand Platform and Ecosystem" is one key initiative within the European AI strategy laid down by the European Commission in April 2018 when it published "Artificial Intelligence for Europe", which aimed to create a first-of-its-kind on-demand AI platform designed to foster cooperation and collaboration between AI communities. The AI4EU industrial committee focuses on three tasks:

- Influence the content and nature of the AI4EU platform development and scaling-up.
- Participate actively in the definition of the open calls and pilots that will put the platform to the test:
 - Open calls are the tools used by the platform to select promising startups around critical AI domains for the future of European industry.
 - Pilots are projects that gather the best of European research and industry to solve AI problems currently impeding the development of products or services.
- Interact with the scientific community to understand and define the challenges that European research will need to address in the future, and provide input from industry to the European Strategic Research and Innovation Agenda (SRIA).

Aviation/ATM is already implementing specific actions to attract AI experts such as funding hackathons (e.g. the SESAR Digital Sky challenge), competitions and industry challenge-driven research missions (e.g. Airbus AI Gym). The regular SESAR open calls for exploratory research and very large-scale demonstrations are also privileged instruments that support interdisciplinary and multi-stakeholder research projects and shorten the time-to-market of promising solutions. These actions should be intensified with a specific focus on AI. The ENGAGE Thematic Network can serve as a platform for facilitating communication and integration between the aviation/ATM and AI R&D communities. The focus is two-fold: inspiring new researchers, and helping to align exploratory and industrial research through a wide range of activities and financial support actions.

Looking forward, there is a strong need to build an inclusive aviation/ATM ecosystem for AI where multiple sectors can come together and develop common solutions, combining multiple capabilities and data sources, while using AI-enabling infrastructure.

TAKE AWAY

The aviation/ATM community should build-up an inclusive AI aviation/ATM partnership by:

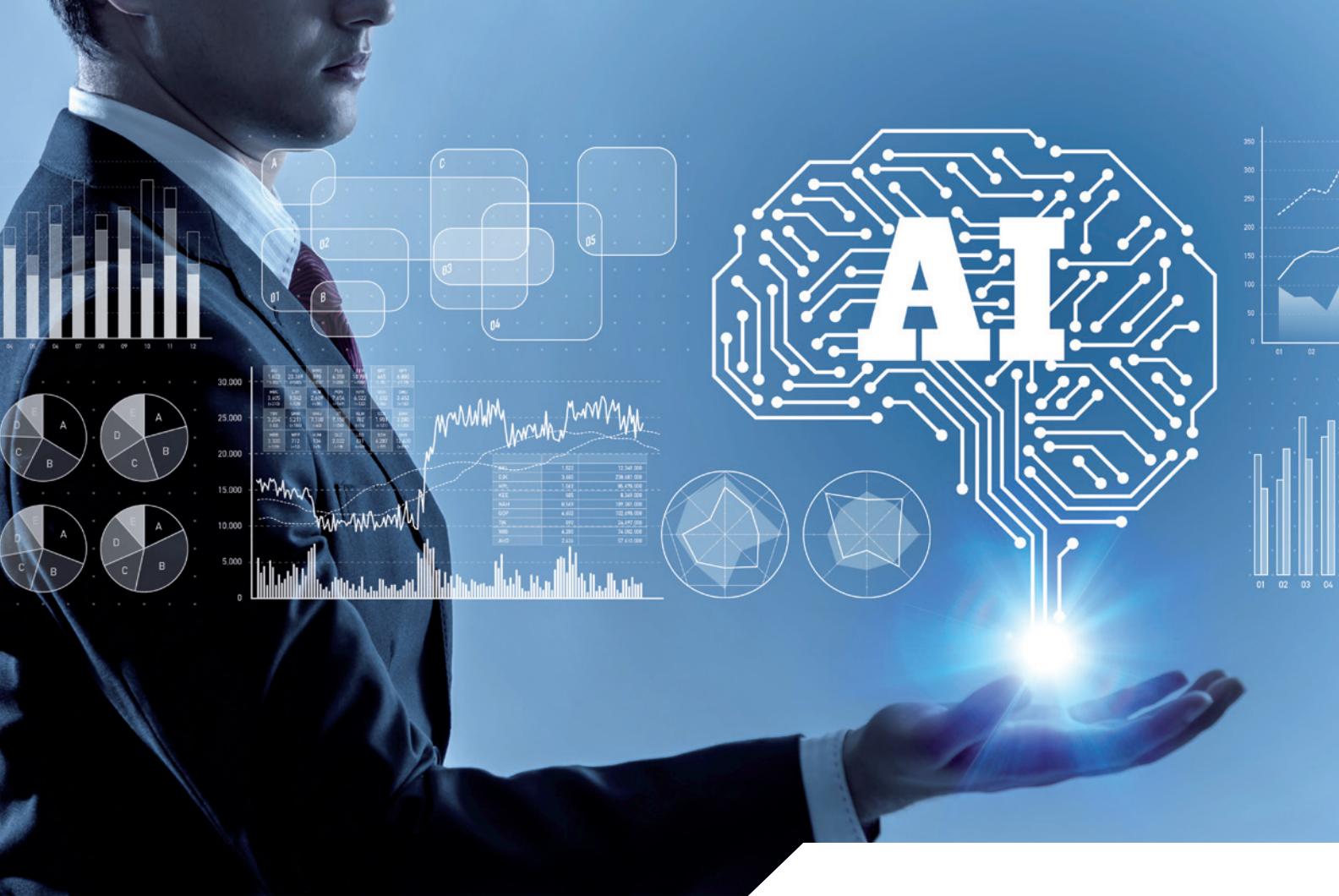
- Creating the conditions for AI-enabled innovations to emerge in the aviation sector,
- Strengthening the connection between European Aviation/ATM and the AI community in particular for start-ups and SMEs,
- Earmarking sufficient financial resources to support the transformation of European enterprises to embrace AI-enabled solutions,
- Providing dedicated, significant and long-term resources and projects for both fundamental and purpose-driven research on AI, with the aim of maintaining the competitiveness of European research and companies, and to address relevant societal and industrial challenges.

Furthermore, to ensure better visibility from the AI community, communication on AI current and future developments in aviation/ATM, and their huge data exploitation potential, should be reinforced. As already successfully developed in the context of drones, an aviation/ATM AI community for exchange should be established.

TAKE AWAY

The aviation/ATM community should enhance its communication on AI by:

- Increasing communication on the benefits of AI for aviation, and encourage aviation/ATM actors to hire AI specialists/data scientists, or partner with external AI specialists on aviation use cases
- Establishing an AI community for exchange to share lessons learned and develop guidelines based on best practices.



10. FLY AI: AN ACTION PLAN FOR EUROPEAN AVIATION

AI is and surely will be instrumental in addressing the challenges that European and Global aviation is confronted with in the areas of capacity, complexity, sustainability, and digital transformation.

To foster a fast track market introduction of AI based applications, and optimally contribute to the buildup of a Single Digital Sky, we need to go beyond the EC promoted notion of a "Digital Innovation Hub"²², and create an AI Aviation/ATM ecosystem that reflects all take-aways (grouped here below in accordance to development lifecycle phases):

22 <https://ec.europa.eu/digital-single-market/en/digital-innovation>

RECOMMENDED ACTIONS	
Data & AI infrastructure framework	<p>As a key enabler to AI-based solutions development, a federated data foundation and AI-infrastructure should be established respecting the following key principles:</p> <ul style="list-style-type: none"> ■ The establishment of a data governance to ensure that the community is collecting, storing and using data appropriately to create shared value, ■ The sharing of data whilst respecting the following principles: self-determined control over stored and processed data and decision on who is permitted to have access to data, ■ The collection by an ATM data community of all available operational data in the federated network of data lakes, ■ The archiving of all real-time data to support the training phase of AI/machine learning developments, ■ The use of open data exchange standards, ■ The nomination of federators in charge of collecting and curating data, ■ Data generated from collective data sets, being fed back to the collective data sets, ■ The ATM Information Reference Model to be used as a baseline to build a common and unique aviation /ATM ontology, to ease data preparation process, ■ An easy access to computing power through the AI-infrastructure
Research and Innovation	<p>Strengthen further exploration of the potential of AI in aviation/ATM in areas with high impact on aviation/ATM performance and environment, human-machine collaboration, safety-critical operations, and safety and cybersecurity:</p> <p>High impact on aviation/ATM performance and environment: priority of new AI-applications should be given to those with highest aviation/ATM performance and environmental impact.</p> <p>Human-Machine Collaboration: establish an efficient, safe and secure Joint Human Machine System where AI-based solutions can be identified to the end user; this should help enhance the human capability to analyse the situation and retain core skills. This includes:</p> <ul style="list-style-type: none"> ■ Developing AI-Human interaction models to support the design phase of the most advanced AI applications (i.e. reasoning , resolution, decision-making, etc ...), ■ Developing verification technics to assess user trust in the new AI-based system behaviour at any stage of the lifecycle ■ Assessing ethical, legal, societal impacts, levels of trust, new tasks, roles and responsibilities of the end user in an AI-based JHMS, ■ Developing explainable AI components to ensure its acceptability including certification, ■ Assessing human factors performance when AI is being used for higher levels of automation/ autonomy or for more advanced decision/reasoning tasks evolving from AI enhancement to AI augmentation, ■ Exploring AI in automation research to assess whether and in what ways AI can be used in a highly automated environment to deliver substantial and verifiable performance benefits while at the same time fully addressing safety concerns and human's skills. <p>Safety-Critical Operations:</p> <ul style="list-style-type: none"> ■ Further explore AI potential in safety-critical operations, ■ Develop new methodologies for the validation and certification of advanced AI applications that will ensure their transparency, robustness and stability under all conditions. <p>Safety and cybersecurity:</p> <ul style="list-style-type: none"> ■ Further develop safety intelligence tools, ■ Explore, customise and develop usage of novel technics based on machine learning for cyber threat intelligence services in aviation/ATM.

RECOMMENDED ACTIONS	
Validation and standards	<p>Appropriate AI validation methods and tools should be developed as well as standards and guidelines. The aviation/ATM community should:</p> <ul style="list-style-type: none"> ■ Further develop testing and validation capabilities for operational environments to help reduce AI-based application time to market, ■ Develop appropriate standards for AI data (data exchange, quality, metadata, ...) as well as means of compliance for AI applications certification, ■ Include cyber-dimension in the Trustworthiness demonstration of AI-based applications for non-safety and safety critical operations, ■ Develop specific AI-based guidelines capturing and further developing safety procedures for safety and non-safety-critical AI-based solutions covering the full aviation/ATM operational scope, ■ Develop guidance on how to treat out the various types of data, ■ Adapt ATM/ANS safety cases to AI-based solution specificities. This would require: <ul style="list-style-type: none"> • Reconciling certification with the need to frequently update AI algorithms, • Creating the necessary processes, procedures and tools to check algorithms and especially trained/implemented AI 'solutions' – on premise or in the cloud – to ascertain that they are trained, integrated and maintained properly, and deliver the intended results without unintended side effects • Filling in the expertise gap between designers/developers and regulators when it comes to adopting AI in an aviation/ATM context, • Reviewing and adapting the current approach to produce an accurate and trustworthy safety case, • Adopting a verification/validation approach based on probabilistic analysis (convergence to a solution within a given deadline), ■ Consider the need for, and the extent of, adapting the liability regimes for companies providing AI software, in particular if performing high-level decision-making functions normally performed by human ATCOs/pilots, ■ Consider the extent to which the 'ATCO/pilot' licensing logic could be extended to the validation/certification of software encapsulating AI-based algorithms (in particular those related to machine learning).
Deployment	<p>The rapid uptake of AI-based solution in operations should be encouraged in the cybersecurity domain and non-safety critical operations:</p> <p>Non Safety Critical Operations</p> <ul style="list-style-type: none"> ■ Further exploitation of AI potential in non-safety critical operations should be encouraged notably when it could improve Aviation/ATM performance and environmental impact. <p>Cyber security</p> <ul style="list-style-type: none"> ■ Increasing the cyber protection of all its data sources as an immediate action, ■ Using and deploying common mature AI-based agile cyber tools for Aviation/ATM to cover operational European aviation and ATM network needs (e.g. the European Aviation SOCs, threat intelligence centers), ■ Secure collecting, secure storing, managing and maintaining cybersecurity data sets for Aviation/ATM AI-based developments in a systematic, harmonized, processable and decentralized way, ■ Assessing the need to adapt Aviation/ATM cyber security governance and policies framework to adopt AI. <p>Speed up AI implementation:</p> <ul style="list-style-type: none"> ■ To remain in the race in the face of rapid international developments in the field of AI, in particular in aviation/ATM, European aviation/ATM actors should aim to reduce significantly the time it takes to bring AI-developments to market.

RECOMMENDED ACTIONS	
Communication and Dissemination	<p>The aviation/ATM community should enhance its communication on AI by:</p> <ul style="list-style-type: none"> ■ Increasing communication on the benefits of AI for aviation, and encourage aviation/ATM actors to hire AI specialists/data scientists, or partner external AI specialists on aviation use cases, ■ Establishing an AI community of practice to share lessons learned and develop guidelines based on best practices. ■ A regular technology scouting of European AI aviation/ATM applications developments and deployments progress should be performed and their (potential future) performance improvement should be assessed.
Training and change management	<p>In line with EC AI HLEG recommendations, an AI culture through training/re/upskilling and change management should be developed. It should rely on:</p> <ul style="list-style-type: none"> ■ A knowledge based tool box to help: ■ Identify AI business-specific opportunities, ■ Plan for resources (skills, training, computing capabilities, data management), ■ Specific Aviation/ATM training, reskilling and upskilling programs including: <ul style="list-style-type: none"> • Customised training suitable to introduce staff to AI (e.g. AI developers, AI users) and at all levels in the organisation (executive, managers, domain specialists, data scientists), • Dedicated aviation/ATM – AI training programmes, covering AI-based systems, the new threats they bring, and failure mitigation measures, • Regular training courses and technology watch to tackle the rapid evolution of AI technology (in particular cybersecurity aspects), ■ HF discipline which should be harnessed and integrated into AI-based applications design programs, ■ European AI aviation/ATM master classes, sharing lessons learned and best practices, ■ Awareness & demystification campaigns regarding AI technics and associated cyber risks.
Partnership	<p>The aviation/ATM community should build-up an inclusive AI aviation/ATM partnership by:</p> <ul style="list-style-type: none"> ■ Creating the conditions for AI enabled innovations to emerge in the aviation sector, ■ Strengthening the connection between European aviation/ATM and the AI community in particular for start-ups and SMEs ■ Earmarking sufficient financial resources to support the transformation of European enterprises to embrace AI-enabled solutions, ■ Provide dedicated, significant and long-term resources and projects for both fundamental and purpose-driven research on AI, with the aim of maintaining the competitiveness of European research and companies, and to address relevant societal and industrial challenges.

Table 2: Recommended actions

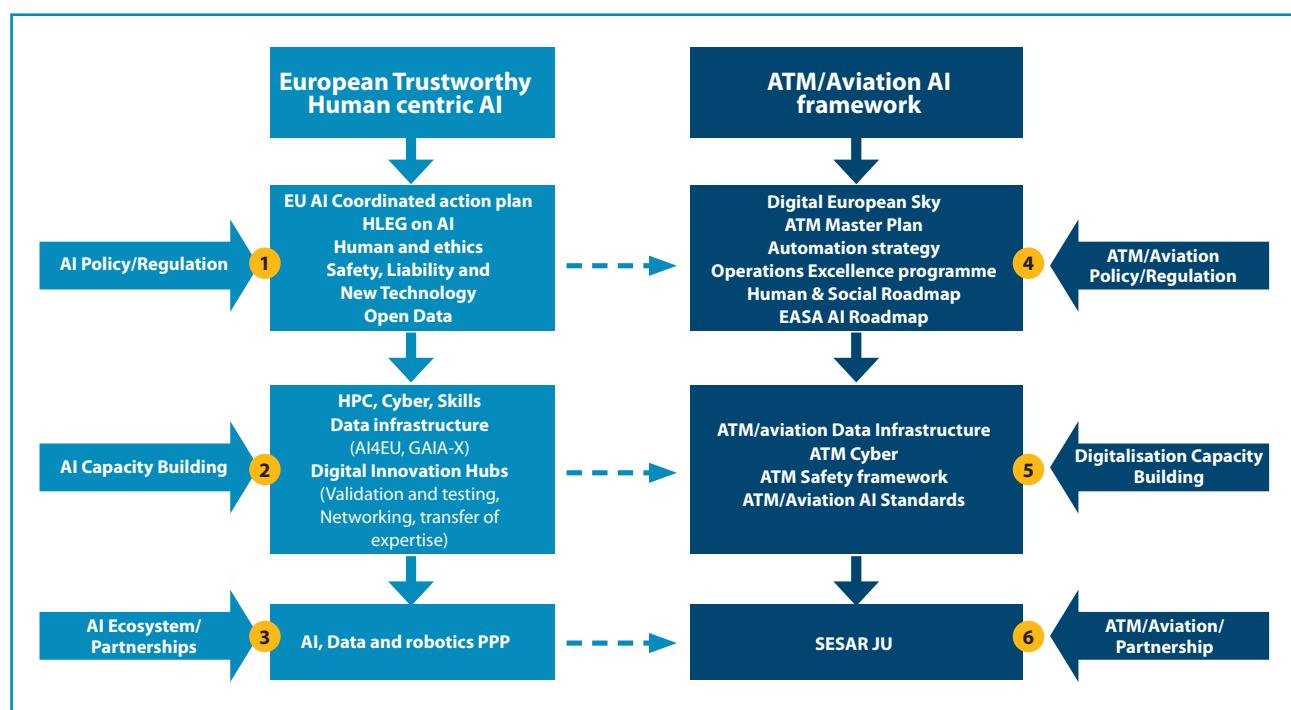
Furthermore AI/ML developments should respect the following principles:

- **Building multi-disciplinary design teams** including operational end users, aviation specialists, human factors specialists, AI and data analytics specialists, etc.,
- **Selecting appropriate conditions for AI-based application evaluation:** day-to-day operations and non-nominal situations

- Relying on AI to **compensate for the scarce resources**
- **Integrating AI into the design phase**
- Ensuring that the scope of correlation of AI/ML algorithms for cybersecurity purpose is extended to cover physical security (e.g. manual manipulations of data)

ANNEX 1: EUROPEAN UNION LANDSCAPE FOR AI IN AVIATION/ATM FURTHER EXPLAINED

The European Union and its Member States have launched a number of initiatives (depicted in blue below– item 1 to 3) to strengthen and drive the development of artificial intelligence in the European industry and for European citizens respectful of European values. Moreover, artificial intelligence underpins the development of the European Aviation/ATM digitalization notably the SESAR high levels of automation. In this context the AI-related actions and areas of activities are depicted in purple. A short description of each initiative is provided in this annex.



1. AI POLICY/REGULATION

To stay at the forefront of the AI technological revolution, ensure competitiveness and shape the conditions for its development and application, the European Commission has put forward a European approach to AI based on three pillars:

1. Being ahead of technological developments and encouraging uptake by the public and private sectors
2. Prepare for socio-economic changes brought about by AI, and
3. Ensure an appropriate ethical and legal framework.

Overall, the ambition is for Europe to become the world-leading region for developing and deploying cutting-edge, ethical trustworthy and secure AI, promoting a human-centric approach in the global context.

This ambition has been further developed by the European Commission in the 'Artificial Intelligence for Europe'

communication in April 2018, followed in December 2018 by the ‘Coordinated Plan on Artificial Intelligence’, providing a strategic framework for national AI strategies. Moreover on 19 February 2020, it published a White Paper aiming to foster a European ecosystem of excellence and trust in AI and a Report on the safety and liability aspects of AI” : https://ec.europa.eu/info/sites/info/files/commission-white-paper-artificial-intelligence-feb2020_en.pdf

■ EUROPEAN UNION COORDINATED ACTION PLAN ON AI

In December 2018, The European commission released a communication²³ regarding the development of a **Coordinated Action Plan on Artificial Intelligence**. The coordinated plan builds on a declaration of cooperation that was signed by all EU Member States and Norway in the context of the Digital Day 2018. The need for coordinated action has been identified in the fields of investment, excellence in and diffusion of AI, data availability, societal challenges, ethics and the regulatory framework. Actions concern both private and public sectors. Of specific interest is the action area called : **From the lab to the market** which identifies three main streams **supporting the acceleration of AI uptake** : 1) Building up research excellence through networks of AI research excellence centers, 2) establishing world-reference testing facilities, 3) accelerating AI take-up through Digital Innovation Hubs.

Data is also addressed as the cornerstone for AI with the objective to create a Common European Data Space. Within this scope, Member states have engaged to:

- Identify public data sets to be more openly reusable across the Union, especially those suitable for training AI applications;
- Support the development and operations of a data infrastructure to enable the management and sharing of data in real-time and the experimentation through a data sandbox of data-driven AI-powered services for governments and public administration at large;
- Ensure the development of the European Open Science Cloud;
- Support the development of secure solutions for giving access to data and securing the integrity of data;
- Support centre for data sharing with the private sector;
- Development of a pan-European supercomputing infrastructure, which will be critical for AI.

■ HIGH LEVEL EXPERT GROUP ON ARTIFICIAL INTELIGENCE

In June 2018, the European Commission established the High-Level Expert Group on Artificial Intelligence (AI HLEG) to support the implementation of the European Strategy on Artificial Intelligence. The AI HLEG was tasked to elaborate recommendations on future-related policy development and on ethical, legal and societal issues related to AI, including socioeconomic challenges. The AI HLEG has published two documents:

- **Ethics Guidelines on Artificial Intelligence:** The Guidelines put forward a human-centric approach on AI and list seven key requirements that AI systems should meet in order to be considered trustworthy: 1) Human agency and oversight, 2) Technical robustness and safety, 3) Privacy and Data Governance, 4) Transparency, 5) Diversity, non-discrimination and fairness, 6) Societal and environmental well-being, and 7) Accountability. Organisations working on AI were invited to test the assessment list of the Ethics Guidelines for Trustworthy AI in a pilot phase ending in December 2019.
- **Policy and Investment Recommendations:** Building the ethics guidelines, the group has put forward 33 recommendations that can guide Trustworthy AI towards sustainability, growth and competitiveness, as well as inclusion – while empowering, benefiting and protecting human beings. The recommendations will help the Commission and Member States to update their joint coordinated plan on AI at the end of 2019.

■ HUMAN AND ETHICS

European Commission President Ursula von der Leyen has announced that the Commission will soon put forward further legislative proposals for a coordinated European approach to the human and ethical implications of AI.

²³ COM(2018) 795 : Communication from the commission to the European Parliament, the European Council, the Council, the European Economic and social committee and the committee of the regions – coordinated Plan on Artificial Intelligence

■ SAFETY, LIABILITY AND NEW TECHNOLOGIES

2019 saw a useful report published on “Liability for Artificial Intelligence and other emerging digital technologies, Report from the Expert Group on Liability and New Technologies” – New Technologies Formation, European Union, 2019.

■ OPEN DATA

The ‘Open Data Directive’ (Directive (EU) 2019/1024) entered into force on 16 July 2019. The Directive provides a common legal framework for a European market for government-held data (public sector information). It is built around two key pillars of the internal market: transparency and fair competition.

Once fully transposed on the national level, the new rules will:

- Stimulate the publishing of dynamic data and the uptake of Application Programme Interfaces (APIs).
- Limit the exceptions which currently allow public bodies to charge more than the marginal costs of dissemination for the reuse of their data.
- Enlarge the scope of the Directive to:
 - **data held by public undertakings**, under a specific set of rules. In principle, the Directive will only apply to data which the undertakings make available for reuse. Charges for the reuse of such data can be above marginal costs for dissemination
 - **research data resulting from public funding** – Member States will be asked to develop policies for open access to publicly funded research data. New rules will also facilitate the reusability of research data that are already contained in open repositories.
- Strengthen the transparency requirements for public-private agreements involving public sector information, avoiding exclusive arrangements.

In addition, the Open Data Directive requires the adoption by the Commission (via a future implementing act) of a **list of high-value datasets to be provided free of charge**. These datasets, to be identified within a thematic range (**e.g. mobility**) described in the Annex to the Directive, have a high commercial potential and can speed up the emergence of value-added EU-wide information products. They will also serve as key data sources for the development of Artificial Intelligence.

2. AI CAPACITY-BUILDING

As already mentioned in the coordinated action plan for AI, key development areas for AI include High Performance Computing, Cybersecurity, Skills and Data infrastructure. Digital innovation hubs (DIHs) are a key pillar in the European Commission’s “Digitising European Industry” initiative. Such hubs typically provide the following services:

1. Experimentation with new digital technologies
2. Skills and training
3. Feasibility studies, business plans, incubation and acceleration programmes
4. An innovation ecosystem and networking opportunities.

In the Digital Europe Programme, DIHs will be called on to play a key role in capacity-building in the areas of AI, High Performance Computing and cybersecurity. DIHs normally focus on a portfolio of services related to more than one application, sector and technology. Networking of DIHs will allow specialised hubs to offer their competences and resources to others, and conversely to find missing expertise and facilities elsewhere in the network.

Figure 2 depicts the DIH network and competence centre interactions.

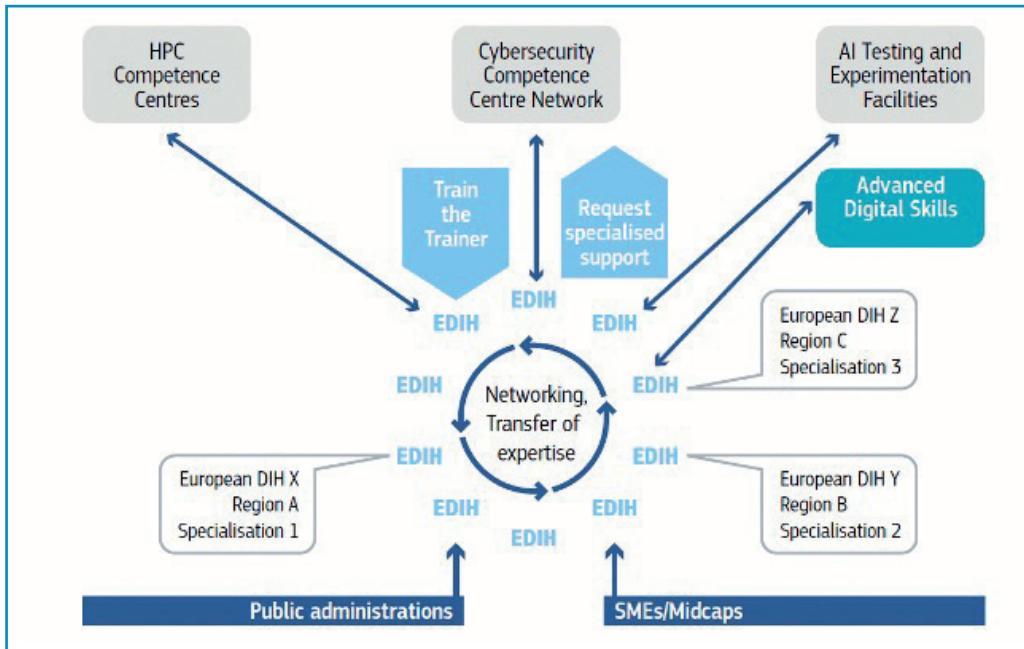


Figure 2: Digital Innovation Hubs Network

■ GAIA-X INFRASTRUCTURE AND ITS SOVEREIGNTY PRINCIPLES

At the Germany's digital summit on Oct 2019, the Federal Ministry of Economics presented the GAIA-X project. The aim of the project is to create a European network supporting all industrial domains, and providing an open data infrastructure that offers companies and authorities independence from large non-European corporations. The aim is to increase data availability for businesses—especially SMEs—in order to better exploit emerging technologies, e.g. AI and Internet of things (IoT).

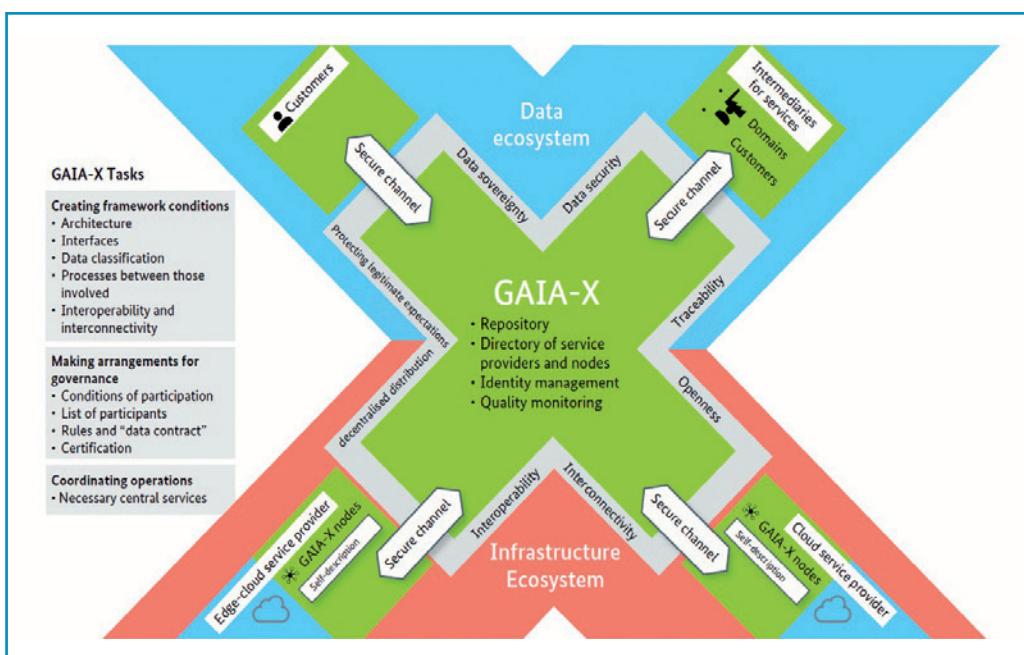


Figure 3: GAIA X data infrastructure and ecosystem

GAIA-X is to be based on digital sovereignty principles:

- self-determined control over stored and processed data
- independent decision on who is permitted to have access to that data.

GAIA-X should:

- offer access to a wide portfolio of digital and cloud-based products and services
- provide high-level interoperability, interconnectivity, security, confidentiality and latency-related requirements
- simplify the management of IT interfaces and integration, especially regarding multi-cloud strategies, data strategies and data pooling.

GAIA-X would be managed by a European organisation with legal capacity.

■ **AI4EU**

In January 2019, the AI4EU “A European AI On-Demand Platform and Ecosystem” consortium was established to build the first such platform and ecosystem with the support of the European Commission under the H2020 programme. The activities of the AI4EU project include:

- **The creation and support of a large European ecosystem** spanning 27 countries to facilitate collaboration between all Europeans actors in AI (scientists, entrepreneurs, SMEs, industries, funding organisations, citizens, etc.)
- **The design of a European AI On-Demand Platform** to support this ecosystem and share AI resources produced in European projects, including high-level services, expertise in AI research and innovation, AI components and datasets, high-powered computing resources, and access to seed funding for innovative projects using the platform
- **The implementation of industry-led pilots** through the AI4EU platform, which will demonstrate the capabilities of the platform to enable real applications and foster innovation
- **Research activities in five key interconnected AI scientific areas (Explainable AI, Physical AI, Verifiable AI, Collaborative AI, Integrative AI)**, which arise from the application of AI in real-world scenarios
- **The funding of SMEs and start-ups** benefiting from AI resources available on the platform (cascade funding plan of €3m) to solve AI challenges and promote new solutions with AI
- **The creation of a European Ethical Observatory** to ensure that European AI projects adhere to high ethical, legal and socioeconomic standards
- The production of a comprehensive **Strategic Research Innovation Agenda (SRIA)** for Europe;
- The establishment of an **AI4EU Foundation** that will ensure a handover of the platform in a sustainable structure that supports the European AI community in the long run.

3. AI ECOSYSTEM/PARTNERSHIPS

Within the Horizon Europe, upcoming EU research and innovation programme a new candidate partnership has been proposed: **the AI, Data and Robotics PPP**. The main objective of the partnership is to boost the development and deployment of AI systems. If retained, it should help structuring the European AI community, develop a strategic research and innovation agenda and federate efforts around this topic of primal importance for European society and economy.

To develop human-centric AI-based systems which are trustworthy, safe, reliable and efficient, major scientific progress are still needed:

- R&I in software (in AI, data analytics, privacy preserving technologies, etc) and in hardware (for safe, efficient and reliable robots); R&I technologies to access and share data (in quantity, quality, diversity, including privacy by design access and data management);
- User-driven validation systems to test the AI in real use-cases and support the take-up of research results-Collaboration mechanisms between the various stakeholders: academia, industry, users, civil society to combat the fragmentation of AI R&I
- Inform and demystify AI through dissemination activities to reach out towards the public and all potential users and individuals impacted; Dissemination towards other relevant communities (e.g.: participation to fairs in application sectors, VC events, etc.).

The Partnership will be in charge of developing and implementing a Strategic Research and Innovation Agenda (SRIA) maximising the benefits of AI for Europe, including the objectives to be reached by Horizon Europe and the milestones and KPIs.

4. AVIATION/ATM POLICY/REGULATION

■ EUROPEAN DIGITAL SKY

In its recently published blueprint²⁴ the Digital European Sky aims to leverage the latest technologies to transform Europe's aviation infrastructure, enabling it to handle the future growth and diversity of air traffic safely and efficiently, while minimising the environmental impact. Central to this digital transformation are increased levels of automation, cyber-secure data-sharing and connectivity. Moreover, AI will enable the virtualisation of infrastructure and air traffic service provision in all types of airspace, ranging from very low to high altitude operations.

■ THE ATM MASTER PLAN

Within the framework of the EU aviation strategy and Single European Sky (SES), the European Air Traffic Management (ATM) Master Plan is the main planning tool for ATM modernisation across Europe. It defines the development and deployment priorities needed to deliver the Single European Sky ATM Research (SESAR) vision.

SESAR vision is to deliver a fully scalable traffic management system capable of handling growing air traffic, both manned and unmanned and enabling airspace users to fly their preferred flight trajectories. This vision is based on a digital transformation of the underlying infrastructure system, characterised by a significant increase in levels of automation and connectivity.

Moreover the ATM Master Plan foresees the need for safety science to evolve to cope with the safety challenges posed by the introduction of machine learning, developing new methodologies for the validation and certification of advanced automation that will ensure their transparency, robustness and stability under all conditions.

■ SESAR AUTOMATION STRATEGY

To meet the SESAR vision, an automation strategy was developed, the 5 levels of automation defined are detailed in Figure 4. The ATC automation model is based on the classic levels of automation taxonomy model used by human performance and safety experts in the SESAR programme. It mirrors the five-level model from the Society of Automotive Engineers (ranging from Level 0, 'no automation', to Level 5, 'full automation')²⁵. Figure 4 presents a simplified view of the overall level of automation in each of the ATM Master Plan phases (A to D) in two different areas: ATC and U-space services. It highlights the steps envisaged towards the profound digital transformation outlined in the Master Plan.

The automation strategy foresees an essential role of AI opening the door to a multitude of innovative applications in automated ATM tasks. Those will be performed collaboratively by hybrid human-machine teams, in which advanced adaptable and adaptive automation principles could dynamically guide the allocation of tasks. ATC and ATFM automation developments will focus on increasing the level of system support, while the initiation of actions will always lie with the human.

²⁴ https://www.sesarju.eu/sites/default/files/documents/digital_european_sky_blueprint.pdf
²⁶ Society of Automotive Engineers Standard J3016, 'Levels of automated driving'.

The goal is not automation per se but optimising the overall performance of the socio-technical ATM system and maximising human performance and engagement at all times. However, the highest automation levels will ultimately remove the human from the loop for selected ATC tasks. Furthermore these levels will enable advanced collaboration paradigms between different human and machine ATM agents. ATC will orchestrate the overall traffic density in collaboration with ATFM, while pilots and on-board automation systems may be allocated specific tasks by delegation. The boundaries between ATC and ATFM will progressively blur, as automation takes on more and more of the tactical ATC tasks and makes it possible to implement more flexible ATFM concepts that rely on advanced tactical support.

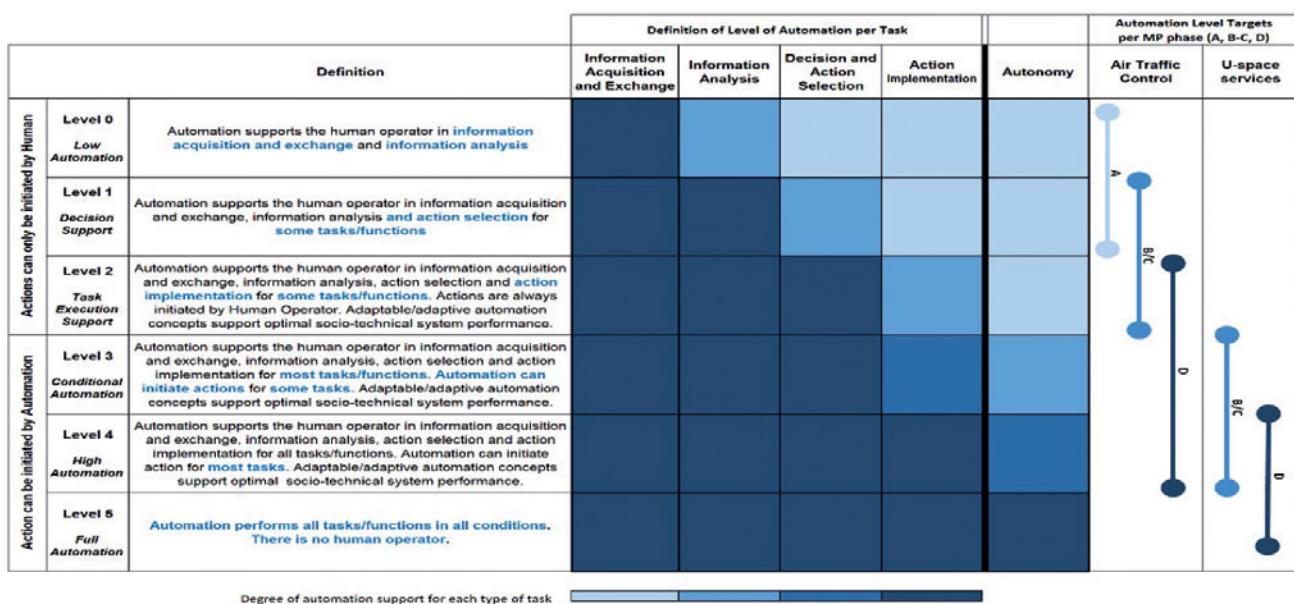


Figure 4: Levels of automation foreseen in the European ATM Master Plan

The synchronisation of the air and ground automation systems should make it possible to reduce both controller and flight crew workload when managing or operating in busy airspace, thus supporting reduced crew operations and RPAS. Automation should also offer safety opportunities, making it possible to progress towards the zero-accident performance ambition in spite of traffic growth.

■ SES OPERATIONS EXCELLENCE PROGRAMME

In 2019, the Airspace Architecture Study was published it aims to support the delivery of a defragmented European sky through virtualisation, ensuring the free flow of data among trusted users across borders ('capacity-on-demand'). A study is ongoing on the legal, economic aspects, certification framework for ATM data service provision (ADSP).

■ HUMAN AND SOCIAL DIMENSION ROADMAP

Given the foreseen traffic and technological evolution by 2035, what will be the likely impacts on ATM staff, in particular on future working conditions, job profiles and required competences? Will the current issues regarding staff shortages be solved? How will the retirement of staff over the next years be compensated by recruitment – will it be sufficient? What are the obstacles to overcome to meet this need for adaptation? How can best practices on how to involve staff in change management and social dialogue be spread across Europe?

The Commission initiated a study on specific social issues and current and future working environment of Air Traffic Controllers (ATCOs) and Air Traffic Safety Engineer Personnel (ATSEPs) in the European Union to collect data on these matters, and identify possible scenarios for evolution.

Building on these findings, the eventual objective is for the social partners in ATM to take ownership and develop a roadmap for policy-oriented recommendations and measures on the human and social dimension of the transition to automation and digitalisation in ATM. This roadmap will accompany the necessary ATM modernisation by proper change management, and will ensure that humans are ready to evolve together with technology, taking benefit of digitalisation in daily tasks, while ensuring as a minimum the same level of safety.

■ EASA AI ROADMAP

In October 2018, EASA set up an internal task force on AI, with a view to developing a roadmap that would identify for all affected domains of the Agency:

- the key opportunities and challenges created by the introduction of AI in aviation;
- how this may impact the Agency in terms of organisation, processes, and regulations; and
- the courses of action that the Agency should undertake to meet those challenges.

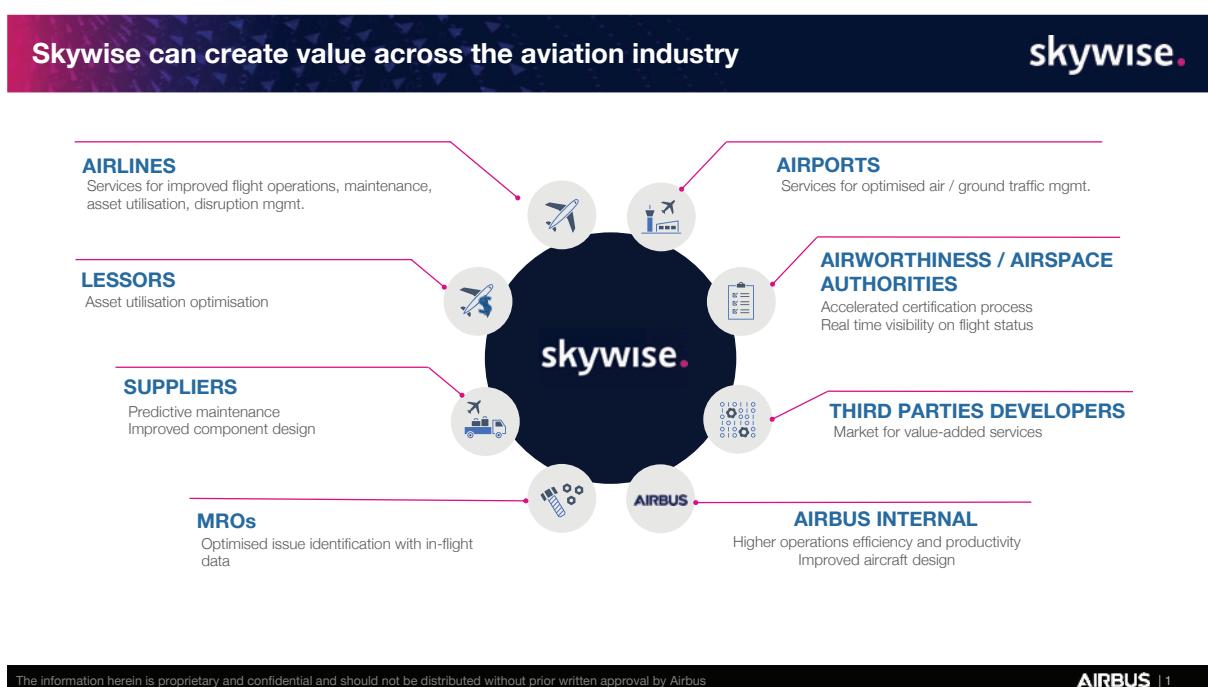
The first edition of the roadmap (<https://www.easa.europa.eu/document-library/general-publications/easa-artificial-intelligence-roadmap-10>) was published on the 7th February 2020.

5. AVIATION/ATM AI CAPACITY BUILDING

■ ATM DATA INFRASTRUCTURE:

Currently, aviation/ATM AI-Based solutions are being developed in different forms and environments which are not interconnected and duplicate efforts in data storing and data management. Some of them serve already different Aviation/ATM stakeholders (e.g. AIRBUS SKYWISE, THALES TOPSKY, DATABEACON, NM B2B).

• AIRBUS SKYWISE: The open aviation data platform for the whole industry



With more than 100 airlines and major suppliers sharing data on Skywise, Skywise is fast becoming the platform of reference for all major aviation players to improve their operational performance and business results, as well as to support their own digital transformation. Various Airports, MRO, Aviation Authorities, or Network planners could be interested to interact with Skywise or share experience around data collaboration, data integration and data governance.

The main outcomes are efficiencies, savings and revenue opportunities achieved by reducing operational interruptions, burning less fuel, operating more efficiently, reducing workload and leaving room for third-party services.

Aircraft have always collected many different kinds of data. In today's era of Big Data and an ever-increasing number of on-board sensors, a true wealth of knowledge is building up – and Airbus has stepped up to mine this valuable resource to further increase the sustainability of aviation.

Through Skywise, Airbus delivers to its customers a platform dealing with complex information. This means providing a high level of security. Skywise General Terms of Use guarantees the confidentiality of data. Skywise was designed to make data integration, access, and analysis seamless for users while enforcing the highest levels of security and access controls across each level of the platform – from data connection to folder permissions and more. Each data has its own data policy and Airbus guarantees that only authorized users can access it according to its data policy.

• Thales TopSky Data Platform

Thales TopSky Data Platform is a data collection and aggregation platform close to operational ATC systems that provides AI services for monitoring and optimization of ATC centres. This R&D platform was developed by Thales as an answer to its customer's needs of increased efficiency and resilience of their operations. It offers fast access and meaningful visualization and exploration of large amounts of data by aggregation of information from different data types, as well as representative user-defined KPIs. Advanced Machine Learning algorithms facilitate the increase of operational efficiency and capacity, enhance flow management functions, and provide infrastructure monitoring. It offers to customers the opportunity to access these clean data and create their own ML models. Anonymous data set generation is possible for sharing with third parties.

• DATA BEACON:

Data Beacon is an open platform focusing on data ownership, confidentiality and data protection. This research platform was developed in the framework of the SAFECLLOUD H2020 project. It facilitates collaboration with third parties without compromising control of private data, and allows airlines, airports, ANSPs and regulators to explore together data solutions without sharing their different data assets.

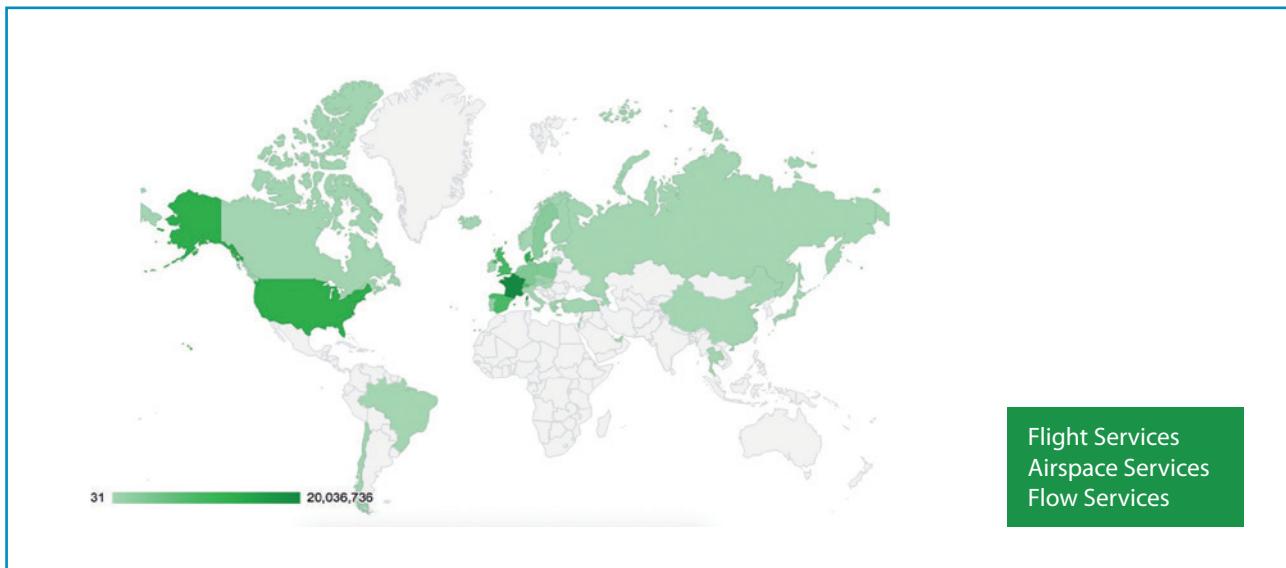
• DATA4SAFETY :

On the 31st of March 2017 the European Aviation Safety Agency (EASA) launched the Data4Safety Programme which aims at changing from the current reactive approach to safety – which is based on accident and occurrence reports – to a proactive approach, analysing trends and situations which can lead to a safety hazard. Stakeholders within the aviation community will share data, information and knowledge in order to deliver safety benefits. Data4Safety will merge the very large and growing number of data sources available in the European aviation system and provide a critical mass of data. Analysis capabilities will be significantly increased thanks to the sharing of large amount of data and the use of the most advanced information and communication technologies in the fields of Big Data and Data Mining. The Data4Safety members signed a programme charter which lays down the principles of collaboration, voluntariness, confidentiality and Just Culture.

• NM B2B WEB SERVICES:

NM B2B web services is an interface provided by the EUROCONTROL Network Manager (NM) for system-to-system access to its services and data, allowing users to retrieve and use the information in their own systems. These services are at the core of the NM Interoperability Strategy, and follow the Single European Sky Aviation Research (SESAR) and the International Civil Aviation Organization (ICAO) System-wide information management (SWIM) principles, which aim at achieving real-time information exchange at a global level for ATFCM). The benefits of such an open ATM digital collaborative environment include data quality and accuracy, timeliness of information, simplification of processes, cost reduction and safety.

These services are made available mainly to ANSPs, aircraft operators, airports, ground handling agents, computerised flight plan Service providers (CFSPs) and airspace management cells (AMC).



The EUROCONTROL NM is already acting as a catalyst for ATM digital transformation, and has seen a very significant increase in its operational data access to NM B2B in recent years, with message exchanges in the dozens of millions a day. With its open SWIM standard services, EUROCONTROL is already responding to the needs of more than 37 countries worldwide in terms of data and global interoperability. The NM B2B dispatches several Terrabytes of data monthly to 239 organisations in 45 countries.

■ ATM SAFETY FRAMEWORK

The aviation safety framework is being advanced under the EASA AI roadmap as well as through the development of a new standardisation activity within EUROCAE, as explained below.

■ AVIATION/ATM AI STANDARDS

EUROCAE WG-114 on “Artificial Intelligence” has as its primary scope to prepare technical standards, guidances and any other material required to support the development of systems and the certification of aeronautical systems implementing AI technologies. The objectives of the working group are to:

- Develop and publish a first technical report to establish a comprehensive statement of concerns regarding the current industrial standards. This first deliverable should clarify the future scope of applicability.
- Develop and publish EUROCAE Technical Reports for selecting, implementing and certifying AI technology embedded into and/or for use with aeronautical systems in both aerial vehicles and ground systems.
- Act as a key forum for enabling the global adoption and implementation of AI technologies that embed or interact with aeronautical systems.
- Enable aerospace manufacturers and regulatory agencies to consider and implement commonsense approaches to the certification of AI systems, which unlike other avionics software have fundamentally non-deterministic qualities.

An SAE group was also formed. Both EUROCAE and SAE groups have now joint efforts.

■ ATM CYBER

Within the framework of EUROCAE WG-114 on artificial intelligence, a number of actions have recently been recommended in order for cybersecurity not to be overlooked for the certification of AI. EUROCAE WG-114 G-34 recommends to:

- identify the security vulnerabilities that are specific to AI systems and check if existing standards enable identifying and managing these vulnerabilities
- if some vulnerabilities are not addressed by existing standards, develop the necessary guidance or ask other working groups to create / update relevant standards; and
- liaise with cybersecurity standardization working groups, for example SAE G-32 and EUROCAE WG-72, in order to ensure consistency of the standards.”

6. ATM ECOSYSTEM/PARTNERSHIP

The SESAR Joint Undertaking (JU) is a truly international public-private partnership. Founded by the European Union and EUROCONTROL, today SESAR unites the whole aviation community through its 19 members. Several members are made up of consortia and, together with their affiliates and sub-contractors, around 100 organisations are today actively participating in and demonstrating the impact of the SESAR programme on ATM R&D activities in Europe. The link with other research communities such as AI is mainly established through exploratory research activities which are published under open calls.

Horizon Europe, the next research and innovation framework programme, is still under discussion. Among the 44 proposed new partnerships, there is one on Integrated ATM. Horizon Europe is expected to introduce three types of partnerships: Co-programmed European Partnerships, Co-funded European Partnerships, and Institutionalised European Partnerships. It is not yet known which type of partnership will be proposed, nor if the partnership will facilitate a connection with the AI community.

ANNEX 2: CATALOGUE OF AVIATION/ATM AI-BASED APPLICATIONS

1. PASSENGER TRANSFER IMPROVEMENT - HEATHROW

London Heathrow airport has deployed a machine-learning tool following a successful study, led by EUROCONTROL in early 2016 with the cooperation of London Heathrow, University College London (UCL) and Darden Business school. The related decision support tool enhances key passenger transfer processes through data-driven predictions and the associated ML algorithm.

Implementation followed a successful live trial that was used to support decisions on to their next gate or advising them to go to their moving passengers company to rebook a later flight.

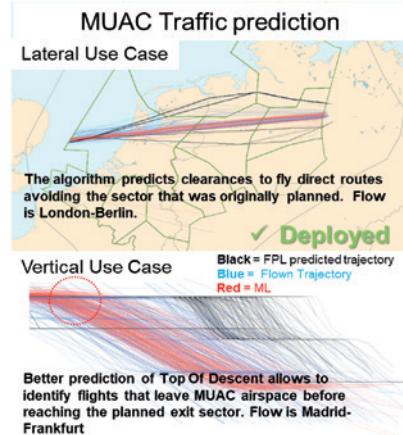
2. TRAFFIC PREDICTION TO OPTIMISE ATCO'S TIME USAGE - ECTL MUAC

EUROCONTROL Maastricht Upper Area Control Centre also uses machine learning to predict 4D trajectories. Project Manager Herbert Naessens says the 4D trajectory includes aircraft position, altitude and speed and already provides more accurate predictions. "We have an advanced prototype which we are considering for operational implementation."

The **Traffic Predictions Improvements (TPI)** project at EUROCONTROL MUAC aims at improving predictability of traffic, allowing MUAC to optimise the usage of ATCOs time and to reduce uncertainty of capacity predictions. To achieve the goal MUAC uses both traditional methods, like improved monitoring of departing traffic using ADS-B data, and innovative artificial intelligence (AI) methods.

Route prediction

Several uncertainties hamper the accuracy of predicted flight trajectories, such as future air traffic controller clearances that will cause the flight to deviate from the original flight plan. By using modern AI algorithms these deviations can be predicted. MUAC launched the initial version of TPI in January 2018, starting in the Brussels sector where a large military area was affecting sector flight planning. The tool has proved very successful, leading to improved predictions for flights between specific city-pairs. For example, average lateral error halved between city-pairs: London Heathrow-Berlin Tegel and London Heathrow-Copenhagen as a result of more accurate forecasts of the sector sequence. The tool was one of the first implementations of AI in an operational ATM system.



4D trajectory prediction

In the next stage of the TPI project MUAC looks at trajectory prediction with the added dimensions of time and vertical movements. Rather than addressing specific elements of the prediction individually (e.g. route, entry point), the AI algorithm takes the full output of the existing deterministic trajectory prediction logic embedded in legacy systems and transforms the predicted trajectory to a more accurate forecast taking into account additional data. The AI technology combines elements from image transformation (Convolutional Neural Networks) and language translation (Recurrent Neural Networks).

The AI algorithm also supports ‘what-if’ functionality, allowing the user to tentatively probe the impact of regulations or military area reservations on the predicted trajectory.

An advanced prototype has been developed that is being considered for operational implementation. Results to date show a benefit of more than 47% for horizontal accuracy, while the average accuracy of the vertical predicted trajectory improves more than 27%. The figures apply to flights not yet in the MUAC airspace, which often suffer from inaccurately predicted trajectories.

In the most recent development of the trajectory prediction tool, MUAC has added surveillance data to develop the tool into more of a real-time solution. Although existing deterministic prediction methods already adapt the prediction based on the observed position, and perform reasonably well horizontally, the AI algorithm can still outperform them.

The benefits are twofold. On one hand, the tool predicts traffic one or two hours in advance when and where a flight is going to enter a sector, providing the flow management position with the expected work load and allowing to decide on optimal regulations. On the other hand, it looks at a shorter horizon of about 30 minutes and provides the Advanced ATFCM Planning Function (AAPF) with predicted clusters or bunching points.

Sector sequence prediction

Differences exist between the sectors that are geographically crossed by a flight and the sectors that take control of the flight, even after accounting for documented deviations (such as hand-over procedures in Letter Of Agreements with other ATC units). Differences stem from working habits of air traffic controllers that are driven by traffic patterns. An AI algorithm is being developed that predicts, for a given trajectory, which sectors will take control of the flight and which sectors will be skipped/bypassed. Aim is to improve sector workload predictability.

3. MAINTENANCE COSTS AND FUEL OPTIMIZATION - HONEYWELL

The Honeywell Forge ML based tool allows airlines to save up to \$200,000 per aircraft per year in fuel costs and up to \$40,000 per aircraft per year in maintenance costs. The tool is a technology stack capable of collecting, cleaning and analyzing wide swaths of data from a variety of airline sources for predictive analytics. The integrated software solution combines a range of individual aircraft and overall airline data into a dashboard that airlines can customize. In service with more than 100 airlines globally, the tool has already had results, including a 30% reduction in delays and cancellations at Cathay Pacific. The tool also offers benefits in passenger experience, flight operations, ramp operations and fleet operations, including faster Wi-Fi speeds with global coverage, a five percent savings in flight times with Air Traffic Control priority, an improvement in arrival times and dispatch speeds, an up to 25% reduction in troubleshooting time on the ramp and reductions in aircraft turnaround times, and a reduction in operational disruptions by up to 35%.

Honeywell Forge enables airlines to more accurately calculate how much fuel a flight will require – these calculations were often based on estimates previously, resulting in wasted fuel and money. Users of the software have improved their fuel efficiency and have seen annual fuel savings of up to 5%. Given the vast quantity of fuel used by airlines, savings of just a few percent can make a huge difference to an airline’s operational costs. In addition, pilots using fuel efficiency solutions can more easily identify the most fuel-efficient flight plans. Pilots can review previous flight paths in real time and find alternatives, enabling them to take the most direct route and improve flight efficiency. Airline operators can also analyse flight path data to identify where and when large amounts of fuel are being used and to make efficiency-driven adjustments to the airline’s flight plans. Lastly, these services not only offer information about planes and their flight paths, but also about airports. Pilots are able to make strategic decisions when taking off or landing to reduce fuel waste, such as using a single engine to taxi out to the runway or selecting a more direct path as they come into land.

4. GNSS MONITORING – ECTL

A Ground-Based Augmentation System (GBAS) is a civil-aviation safety-critical system that supports local augmentation –at airport level– of the primary GNSS constellation(s). By providing enhanced levels of service it enables all phases of approach, landing, departure and surface operations notably under low visibility conditions.

However, one of the main sources of GBAS GNSS ranging error is the propagation delay induced by a particular layer of the earth's atmosphere: the ionosphere. Thus to overcome this integrity issue a ionospheric model was developed, based on ionospheric data collected over the last decade. In order to support ANSPs when submitting a GBAS approval to their regulator, but also to guarantee the constant validity of the model, EUROCONTROL is continuously monitoring the ionosphere over Europe.

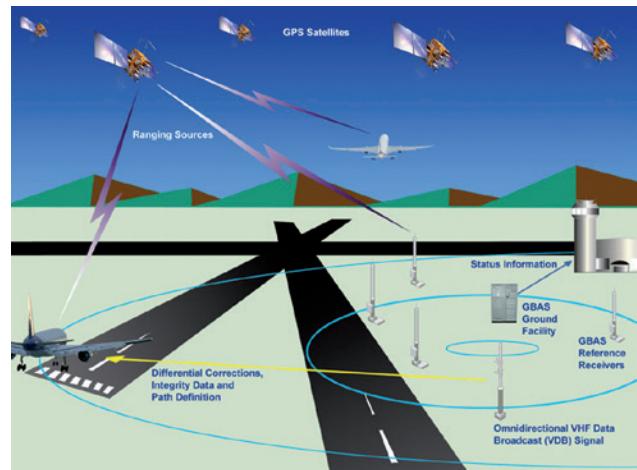
The detection of ionosphere spatial gradient is complex and challenging: a significant amount of GNSS raw data needs to be processed and the current processing techniques provide a large number of "fake" gradients coming from measurement artefacts. As a result, a manual validation of the processing outcomes is required, which represent a significant amount of effort from skilled operators. As output of the current automatic processing, more than 90% of the detected gradients are classified as measurement artefact during the manual validation.

To improve the quality of the automatic gradient detection and reduce the manual effort, Artificial-Intelligence-based algorithm were tested. Since the beginning of this project (October 2012), a total of 16084 potential gradients were manually validated out of which, 1641 were true ionosphere gradients. These gradients represent a valuable database that can support a machine-learning algorithm. The database has been prepared with the objective to overcome two limitations: the number of entry is limited (16000 is small in the machine-learning world), and the database is biased (10% of "True" entry for 90% of "False" entry). These limitations have been mitigated through data augmentation by applying small variation techniques (scaling & reversing).

The machine-learning techniques were used in an "offline" neural network. Once optimized, the best trained neural network was frozen and implemented in the GNSS data processing, improving further the GBAS ionospheric model, without compromising the safety criticality of the approved operation.

The results showed that the best architecture is a mix of the two technics (a convolutional network and a recurrent (LSTM) network), **providing a classification between true gradients and measurement artefact 3 times better than the former processing technique**. The implementation in the operational data processing is planned for Q4 2019.

This AI approach will now be tested and applied to the other CNS monitoring tasks under the responsibility of the Network Manager.



5. AI FOR THE NETWORK

PROPOSE BETTER ROUTES WITH AI

Pathfinder is a Network Manager tool used to proposed routes to Airline Operators. The project's objective is to assess the feasibility and added-value of machine learning models and data science technologies to improve the routes proposals taking into account business needs.

The approach relies on an iterative phasing with a Go-NoGo process that allows a "fail fast – succeed fast" principle. It includes 3 phases (Frame, Create and Convince) of several iterations of 3 to 4 weeks each.

The objective of the Frame phase was to demonstrate that it was possible to use Machine Learning to propose viable flight paths and enhance the efficiency of AOs. The FRAME phase made it possible to determine the scope of the study and to identify machine learning models that could meet the need to improve the route proposal for airlines.

For the preliminary testing of the hypothesis, two city pairs were chosen:

- Route 1: Madrid – London
- Route 2: Catania - Roma

Two models were experimented and fine-tuned (among 6 initial ones pre-qualified) for the two city pairs, one called "Random forest" and the other "Neural Network".

Once the 2 models were trained and tested on the 2 city pairs, the tests were expanded to 30 city pairs.

Using both models on 30 scenarios allowed to test in different conditions. The dataset for a route is always divided in two: Train set and Test set. The train set is used to define the classification model, the classes being here the different set of possible successive waypoints representing the routes. Then the model is evaluated with the test set and accuracy is used to rate the model performance and allows a comparison.

We can conclude that there is not a model that outperforms the other for every metrics and all cases. Thus, the best solution may be to combine models instead of selecting only one. Then, according to the diversity group, choose which model to use. As the diversity is a metric that we can calculate directly from the data, it is effortless to programmatically trigger one or the other model based on this criteria.

The next steps will be to do some complementary tests to assess if we can optimise one of them or if we have to keep both. Then to enlarge the scope to the whole IFPS Zone and prepare the models for industrialisation.

PREDICTION OF TAKE-OFF TIME

The aim of the project is to contribute to the improvement of the demand profile, through a better prediction of the take-off time. These values being related, and given that for the AOBT the delays are mainly induced by NM, the focus of the project is on the prediction through machine learning (ML) and deep learning (DL) techniques.

The objectives of the current phase are:

- Discuss with the user representatives and identify the target(s) to be used for the prediction during the CREATE phase (i.e. one target based on ETOT or a dual target ETOT vs CTOT depending on regulation status).
- Identify most probable model architecture ETOT vs CTOT, CDM vs non-CDM or airports clustering.
- **In terms of objective**, the project shall focus on improving the prediction of the TOT of the ETFMS flight model(s). If the prediction is used in the FTFM model, the other profiles will likely be improved as a consequence, either directly by use of more accurate FTFM data as input or indirectly by improvement of the operations (e.g. less regulations will have to be used, resulting in a better RTFM profile).

- In terms of scope of data, the project shall extract and use time-stamped flight updates stored as part of EFD (ETFMS Flight Data) messages. In addition to the time information (time to take-off), the EFD will allow the access to relevant data that are received as part of DPI messages (transmitted by CDM airports) such as:
 - TTOT (Target Take-Off Time)
 - SID (Standard Instrument Departure), from which Departure Runway could be derived (using ENV mapping where possible)
 - Event Origin (FPL/CHG/DLA, CPR, DPI, etc...)

In terms of work environment, the project shall exclusively use the Azure environment to extract and analyse data with optimal hardware performance. This will required support from DWH team to assist in the search and migration of data to the cloud instance.

There are three possible ways of using the TOT prediction. The recommendation is based on the principle of "protecting" CASA processing against potential infinite loops that may be caused by an AI predictor that would amend a field that is used as an input of CASA after the calculation took place.

With this perspective, two models could be considered trained and tested with the same dataset:

- **ETOT Predictor:** trained against (ATOT - ETOT) target, this model would provide an improved ETOT value based on the initial ETOT (and other features as input). This prediction will then contribute to the improvement of the Demand Profile.
- **CTOT Predictor:** trained against (ATOT - CTOT) target, this model would provide an improved CTOT based on the computed CTOT (output of CASA and other features as input). This prediction will contribute to the improvement of the Regulated Demand Profile, but could also improve the Load Profile as a consequence.
- **CTFM ATOT Predictor:** trained against (CTFM_ATOT - ATOT) target. The CTFM_ATOT is the first value of the RTFM time over.

AUTOMATE FLIGHT PLAN CORRECTION

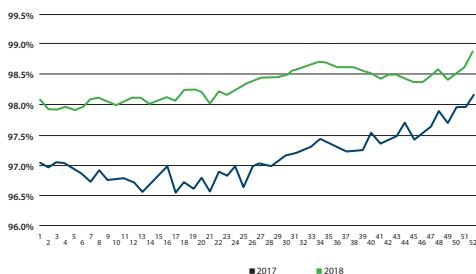
HOW AI HAS ACCELERATED AUTOMATED FLIGHT PLAN PROCESSING

The past few years have seen NM working hard to increase the number of Flight Plans (FPL) that are automatically processed. Each time the system could not process a flight plan it required manual intervention by NM operations staff to analyse and act on the flight request – a time-consuming and expensive business. Evolving the automatic pass rate by traditional methods saw only a very small improvement – NM processed 96.32% of all FPLs automatically in 2014, rising

to 96.79% in 2016. In 2017 data science techniques were introduced to identify specific and complex patterns that could be automated. By the final weeks of 2017, NM was recording automated processing rates of 98%; in the Summer 2019 it had risen to 99.5%. A 1.5% increase may not seem very much, but with more than 30,000 FPLs a day being processed it has meant a significant reduction of workload in the operations room.

Comparison of the automatic flight plan processing rate between 2017 and 2018

Automatic processing rate – Weekly evolution



Comparison of the automatic flight plan processing rate between 2018 and 2019

Automatic processing rate – Weekly evolution



6. IMAGE RECOGNITION TO DETECT RUNWAY VACATION - HEATHROW

The UK air traffic management service, NATS has begun a trial to understand whether Artificial Intelligence (AI) could be used to help reduce flight delays.

A project is now underway, within NATS' bespoke Digital Tower Laboratory, at Heathrow Airport to test whether a combination of ultra HD 4K cameras along with state-of-the-art AI and machine learning technology can be used to help improve the airport's landing capacity in times of low cloud and low visibility and improve punctuality.

Heathrow's 87 metre tall control tower is the highest in the UK and provides commanding views of the airport and surrounding landscape, but its height can also mean it disappears into low cloud, even when the runways below are clear. In those conditions, where the controllers have to rely on radar to know if an arriving aircraft has left the runway, extra time is given between each landing to ensure its safety. The result is a reduction in landing capacity, which creates delays for passengers and knock-on disruption for the rest of the operation.

NATS is deploying 20 ultra high-definition cameras at the airfield, the views from which are then fed into an AI platform called Aimee, developed by the Canada-based Searidge Technologies. The Aimee platform can interpret the images, track the aircraft and then inform the controller when it has successfully cleared the runway. The controller then makes the decision to clear the next arrival.

NATS believes the system will help the airport reclaim all the lost capacity.

Non-operational trials are now underway to understand the feasibility of introducing the technology into service as early as this year. From now until March, Aimee will study the behaviour of more than 50,000 arriving aircraft to ensure the accuracy of the system. The project findings will then be presented to the Civil Aviation Authority.

The trial is part of a £2.5 million investment NATS has made in a 'digital tower laboratory' located inside the Heathrow control tower. There, it is working with the airport to understand how technology could support the air traffic operation now and in the future.

Heathrow Airport are trialling a number of use cases based on AI / ML algorithms, to be used in Operations.

- One case is looking to at using a camera and AI to detect landing gear deployment points. The timestamped image of the moment the gear is fully down can be linked to a radar track and determine the distance from the airfield the gear was deployed. The gear detection system will be used to detect and promote best practice with regards to gear deployment. The later the gear is deployed, whilst remaining safe, the better the noise outcomes are for our local communities.
- Another case is trialling the use of image recognition on the aircraft stands to detect and categorize Foreign Object Debris (FOD) prior to the arrival of the aircraft on stand. This can be integrated into safety alerts to the relevant staff which can take further action.

Finally, British Airways and Heathrow Airport are trialling the use of image recognition algorithms on turnarounds. A few cameras set up near the stand and on the boarding bridge capture images of the aircraft, and AI / ML algorithms detect various timestamps in the turnaround process, such as the moment when the re-fuelling truck arrives, when the boarding bridge has been connected etc. This can add an additional layer of detail and understanding of the turnaround process.

7. FORECAST IMPROVEMENT - ECTL

For the last few years, AI has given EUROCONTROL forecasters a set of highly capable new tools in their predictive analysis toolbox – not all tools work, but when AI does work, the results can be impressive.

Air traffic forecast is reaching new levels of uncertainty with the industry itself becoming less predictable, more prone to sudden swings in industrial, economic and environmental turbulence. However, despite increased volatility, accuracy of forecasts has made small but almost constant improvements. This is primarily due to a better understanding of the air traffic dynamics key patterns, which provide indications of future demand but also to the use of Artificial intelligence (AI) techniques.

The forecasting system is based on a wide number of different components. The STATFOR forecasters isolate the trends, the relationships between the different factors into components, and ultimately improve the quality and performance of the final forecast. For example, they have put a great deal of effort into forecasting zone-pair flows, to determine exactly how many more flights there will be between one zone and another at some time in the future. When they're forecasting air traffic movement in Europe, they're dealing with relatively small numbers of countries, airports, aircraft operators and aircraft types - which means that one event or one decision by a carrier can significantly change the traffic in several countries. However, statistical techniques are reaching their limits and human analysis remains essential.

AI machine learning approach analyses thousands of different types of exogenous data, more than any analyst could make sense of. The machine learning system selects the most relevant data sets.

With new AI algorithms using more input into the calculations than just the core gross domestic product (GDP) data results have been very positive: the tests performed on seven traffic flows across the North Atlantic showed that ML process enabled the reduction of the median absolute error, by between 8.5% to even 71% for some pairs compared to the STATFOR median absolute error, for a specific year. As a result, STATFOR forecasters are about to re-engineer their forecasting toolbox, restructuring the way they undertake forecasts to benefit from AI technics.

However AI is not self-sufficient, AI would struggle to synthesise the information from local experts across Europe. Carefully selected AI technics relying on good datasets and deep knowledge of the local situation can further improve forecasts. Applying these principles, STATFOR forecast experts were able to continuously improve their forecasts. In 2018, the median error per year was small, at 1.1%, and the median absolute error per year was 2.1%, one of the lowest errors ever recorded by STATFOR. The 2018 forecast was 104% more accurate than the same-as-last-year growth baseline.

As turbulences within the Global air travel industry are predicted to grow over the coming years, the importance of identifying and exploiting new AI techniques – and then learning how best to apply them – will also increase.

8. FMS VALIDATION - THALES

Combining extensive knowledge of Avionics, Connectivity, Air Traffic management and 40-year Flight Management System expertise, Thales has developed PureFlyt, an entirely connected FMS, designed to offer airframers and airlines the best combination of safety, security, and fuel and operations efficiency. PureFlyt will allow crews to make better decisions using more sources of information, will bring improved performance and reactivity to the aircraft during complex phases of flight and will calculate alternative trajectories in real time to propose or react quickly to changes of plan. Providing pilots with the right information at the right time heightens trust in the computed trajectory, enhancing efficiency and reducing pilot workload throughout all flight phases.

One of the core innovations making PureFlyt a game changer in the FMS world is its ability to draw on both onboard and open-world data, such as weather information. By combining the integrity of the FMS and the agility and power of Electronic Flight Bag flight functionalities, aircraft trajectory can be permanently controlled, adapted and enhanced, resulting in optimised flight, decreased fuel consumption and improved passenger comfort.

While being a technological breakthrough, PureFlyt enjoys an unparalleled maturity level. Using massive testing and artificial intelligence technologies to simulate 2 billion test cases enabled accumulating an invaluable experience, equivalent of 100 million actual flight hours.

Cyber-secure by design, PureFlyt has also been designed to be future-proof, accommodating the implementation of concepts such as the Initial 4D (I4D) trajectory management methods currently being researched by SESAR (Single European Sky ATM Research) in the EU and NextGen in the US. By increasing the accuracy of flight in four dimensions, the fourth dimension being time, PureFlyt will enable more effectiveness in maintaining optimal distance between aircraft, particularly in the demanding phases of departure and approach.

PureFlyt will be available for entry into service in 2024, for both linefit and retrofit.

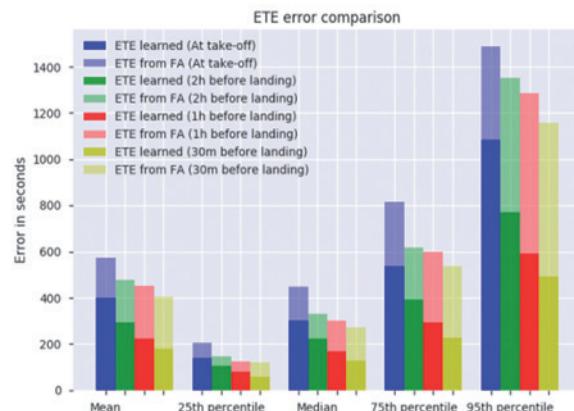
9. TRAFFIC PREDICTIONS – THALES

Predicting the short term future (0-24h) is of key importance for Collaborative Air Traffic Flow Management. Stakeholders are often interested in different aspects: En-Route ANSP will want to know airspace 4D occupancy, Approach/tower will be interested in CTA entry & landing times, Airport will want to know gate arrival time, and airlines will also be looking for holding times & gate arrival times.

Traditional flight mechanics computation using aircraft models, winds & temperature and based on the flight plan, can predict the straight forward part of the trajectory, from take-off to beginning of approach. But flight vectoring make it complex to predict precisely the trajectory as the trajectory is modified in live time to maintain separation and build the landing sequence. Also, taxi times, both before and after the flight, are difficult to predict with traditional algorithms.

For these phases, AI brings a lot of value thanks to its capacity to predict based on historical data. AI can also predict all other phases of flights without use of any flight mechanics computation. In addition, AI can be used as a way to improve the flight mechanics computations, to integrate all deviations to the plan (direct routing, weather deviations...) and also the influence of parameters that are unknown (aircraft weight, cost index setting...).

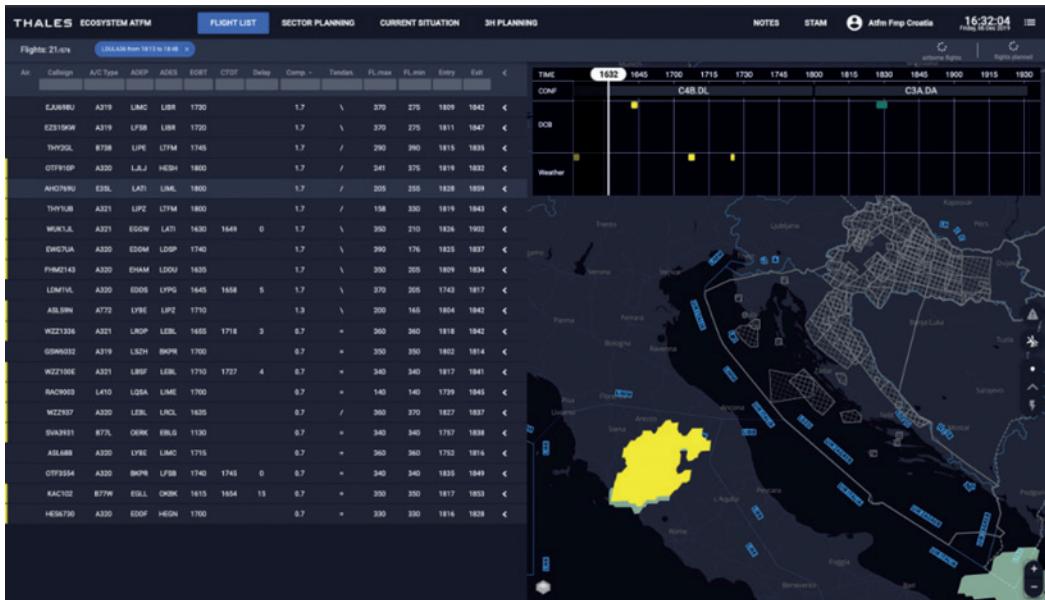
In Thales, we have used deep learning techniques to better forecast traffic: ETA/ETE/ETO/ETOT, FIR and TMA entry predictions in time and altitude, based on historical data, with additional in-flight improvement of predictions. The prediction error is reduced from 30 to 60% compared to classical algorithms used by surveillance data providers. These predictions are available in ECOSystem ATFM and also will contribute to the trajectory prediction in ATC systems as well as for other products, like the AMAN/DMAN sequencer.



10. AIRSPACE COMPLEXITY PREDICTION AND MANAGEMENT – THALES

Airspace complexity is facing two main challenges. First, there is no realistic, tunable and scalable airspace complexity measure. Indeed, each individual actor in ATM may give a different definition of the complexity. So even though we started by proposing a new analytical measure for airspace complexity, considering the 4D trajectories and speeds of all the aircraft in an airspace, the next step was to learn it on a large worldwide database by using deep learning and recurrent neural networks, and then make it tunable by ATCOs, also with ML techniques.

This indicator allows validating the load hotspots, giving to the FMP an additional measure to appreciate the air situation. This flexible measure is therefore able to help in monitoring and predicting ATCO workload by adapting it to the foreseen airspace complexity and thus contributing to the load-demand balancing task.



Moreover, it is possible to predict ATC grouping and de-grouping sectors depending on learned complexity, supporting dynamic airspace configuration for flow management.

A second important challenge using the complexity learnt measure was to predict traffic hotspots per sector and then, using again ML techniques, be able to know which are the trajectories that contribute the most to this perceived complexity.

Complexity reduction in a sector allows a temporary increase of the sector's capacity. In such a reduced complexity traffic, as done with FMP actions, the controller will have more time to manage the flights and remaining conflicts.



11. USE OF AI TO OPTIMISE THE SECTOR CONFIGURATIONS - DSNA

DSNA in France is developing new AI tools to advance operational solutions to deploy the optimal configuration of sectors, and thus to optimise capacity with available resources. European airspace is divided into several elementary blocks of airspace which allow modularity and flexibility in building the different airspace configurations to meet expected and effective traffic flows. In the case of France, its airspace is composed of 168 elementary sectors. In the tactical phase, Supervisors and Flow Management Positions (FMPs) analyse, on a continuous basis, traffic demand and available capacity from the analysis of the operational air traffic control centre (ACC) data, including resources, technical availability, unexpected events and environmental data (weather, military activity). With their expertise, they manually determine the most adequate sector configurations.

Without automation, identifying the sequence of adequate ACC sector configurations according to traffic flows and associated workload is time-consuming. Only solutions from predefined catalogues are routinely used, limiting the possibilities.

DSNA is therefore using innovative techniques, offering dynamicity, optimisation and time-saving in capacity management and ACC sector configuration. In order to maximise the benefits of airspace modularity while optimising resources, automated functions have been developed to support Supervisor and FMP decision-making. A new AI tool is able to optimise airspace solutions in case of high workload and unforeseen events which could require quick decisions for airspace re-organisation. It also provides additional means in the Air Traffic Flow Control Management (ATFCM) toolkit using dynamic sector configurations to facilitate users' preferred routings.

12. RUNWAY OPERATIONS PERFORMANCE PREDICTIONS - ECTL

Recognising the increasing opportunity of data in predictive applications, EUROCONTROL, together with our stakeholders in areas such as airspace, network management and runway management techniques, is actively investigating the use of data analytics to identify performance improvements and benefits.

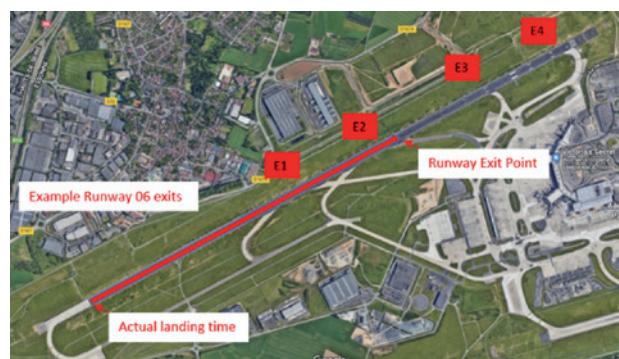
Some early applications investigated the predictability of aircraft turnaround at the gate and Taxi-Out Time (TXOT) in support of performance prediction tools to be used in an Airport Operations Centre (AOC). The expectation is that, with access to accurate data, decision-making is improved and operational staff become more proactive.

One application tested produced TXOT predictions using data from Paris Charles de Gaulle, which improved the prediction robustness compared to traditional statistical analyses. Furthermore, TXOT predictions were quickly computed in a few minutes.

Another application, developed in the EU SafeClouds project, predicted the runway exit to be used after landing during High Intensity Runway Operations in order to help tower controllers judge separation minima between leader and follower aircraft, thus optimising runway occupancy time and reducing potential go-around or missed approaches.

In the runway exit application, a prediction is produced at 2NM from the runway threshold and presented to the controller through a runway tactical support tool. This tool advises the controller of the predicted Arrival Runway Occupancy Time (AROT) and runway exit for each aircraft, helping the controller to anticipate any separation reduction for the following arriving aircraft.

The ML runway exit support tool was based on Vienna airport and tested in a SESAR Real Time Simulation undertaken by EUROCONTROL. Vienna controller Philipp Wächter, who took part in the simulation, said that the "controller support tool for AROT and runway exit prediction was considered operationally feasible and acceptable."



Whilst this work will be continued to pre-implementation level in SESAR, a real-time prototype was later developed and tested with data from Orly Airport with critical wind data provided by a 'Leosphere' Lidar to improve prediction accuracy. Alexandre Sauvage, Head of Leosphere anticipates that, "this approach is really appealing for most large airports and would increase the capacity and safety."

13. TRAJECTORY FORECASTING - DFS

The following activities in the context of AI have taken place or are in the process of development at DFS, the German ANSP:

	Operational Relevance	Status of activities	Further steps / Comments
Improvement of the trajectory forecast for the climb phase of flights in German airspace using AI	High	Preparation of validation, based on live operational data	Trial of trajectory forecast in the operational environment
Project FUTURE - AI-based distance recommendation for aircraft on final approach	High	Ongoing R&D project (Luftfahrtforschungsprogramm, LuFo)	Transfer of results into ATM requirements baseline in 2020/2021
Calculation of Estimated Time of Arrival (ETA) in the Point Merge Arrival System at Leipzig	Medium	Completed	Shutdown with abolition of Point Merge Leipzig; possible use of the principle at other major airports in Germany
Prediction of flight time in the approach phase at Munich Airport until passing the landing threshold	Medium	Completed	Preparatory exercise in the context of the development of a spacing assistant

Improvement of the trajectory forecast related to flight time until touchdown

Using a very efficient and fast AI method based on machine learning, a highly accurate landing time prediction was achieved for flights arriving at Munich Airport (EDDM). Depending on operational conditions and the traffic situation, flight trajectories within the TMA can be very volatile, which makes the results achieved quite remarkable, outperforming conventional arrival calculation algorithms. Figure 1 shows the difference between the real and the predicted remaining flight time until landing vs. the predicted flight time. For example, if predicted landing is in 15 minutes, then 68% of landings will take place within 15.0 ± 1.4 min. and 95% will take place within 15.0 ± 2.8 min. Such values are practically impossible to achieve with conventional computational methods.

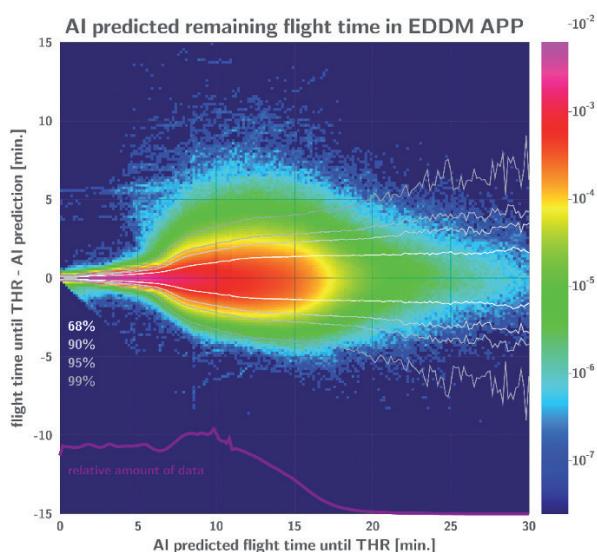


Figure 1: 2-dimensional presentation of AI predicted remaining flight time in EDDM approach compared to the real flight time. Aircraft anywhere in the TMA have been analysed thus covering a time span of up to 30 minutes flight time.

With comparable machine learning methods also the stability of the forecasted arrival sequence can be improved considerably.

Improvement of the trajectory forecast for the climb phase of flight

Of particular interest is the improvement of the vertical part of the trajectory, which seems to be one of the most challenging questions because of the large spread of vertical climb rates and the associated operational and technical uncertainty. The focus of research was on predicting an aircraft's altitude from flight level 100 up to flight level 285 after its initial climb by making use of machine learning methods, e.g. supervised learning in form of a feedforward or recursive neural network.

A successful prediction would be highly advantageous for conflict detection and resolution systems and would generally improve the service quality of Air Traffic Control. Whenever two planes are predicted to come closer than 6 NM on the lateral axis, a vertical conflict calculation is needed. Currently, this is being done by simply taking the most recent rate of climb from radar data with a static buffer of ± 500 feet/minute. This buffer is needed in order to take into account the vertical climb uncertainty and to obtain a good compromise between false alarms and missed alarms.

This buffer potentially increases the alarm rate which results in a higher workload for controllers and perhaps even mistrust in the system. In addition, the airspace cannot be optimally used. Especially when there are three or more aircraft flying close to one another, efficiency is hampered by the rather big buffer.

To reduce false alarms while keeping the rate of missed conflicts reasonably low, a more accurate prediction is needed.

A successful machine learning prediction of the flight level for each individual aircraft might improve all of the above mentioned points, resulting in less manoeuvering and more accurate clearances. Also, for the DFS automation strategy, a more accurate trajectory prediction is one of the key enablers.

To determine concrete potentials of improvement, deep learning with neural networks was applied to predict the aircraft climb behavior with a time horizon of six minutes. The achieved accuracy for two selected aircraft types shows a mean absolute error of about 6 to 7 FL, well below the actual vertical separation minimum of 10 FL (!). DFS concludes that this approach allows to reduce the uncertainty buffers for Decision Support Tools in the climb phase, which is the most challenging part of a flight in terms of trajectory predictions.

The next step in these activities is to feed operational flight history data into the algorithm in real time in order to deduce improvement potentials from a large amount of flight operation data.

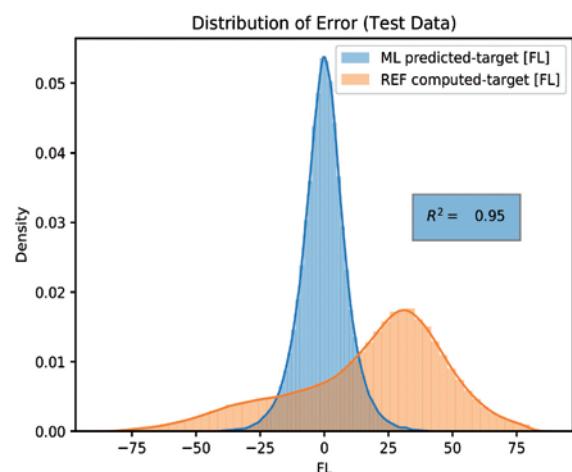


Figure 2: Distribution of Error concerning climb phase prediction. AI based methods proved to be more accurate than conventional methods to predict climb behavior of individual flights.

14. AIRBORNE COMPUTER VISION IN LOW VISIBILITY – SESAR HONEYWELL

SESAR Enhanced Vision Solutions, developed by Honeywell, enable more efficient approach, landing and taxi operations in conditions of low visibility. Studies showed significant advantages for Air Traffic Capacity in bad weather conditions, including reductions in flight cancellations, diversions and delays. Airport benefits, expressed in terms of an increase in the number of possible aircraft landings, are up to 50% of the airport capacity increase. Regional airlines obtain up to 60% improvement to be on time at the final destination, which includes reduction of up to 50% of the delays and cancellations and up to 75% reduction in diversions.

Such systems derive a new source of aircraft positioning assurance from ground features detected through an imaging sensor. This new source of aircraft positioning can be used to improve the integrity of a system whether it is presented in the head-up or head-down location and enable further operational credit. Those imaging sensors utilize more and more AI based techniques to derive human like vision capabilities, even in adverse weather conditions, to allow higher levels of situational awareness and navigation precision.

15. DEMAND AND CAPACITY BALANCING – ECTL/THALES

Balancing demand and capacity is becoming a critical concern given the continued growth in air traffic, yet demand and capacity imbalances are difficult to predict, mainly due to the lack of accurate 4D trajectory information prior to daily operations. Future Trajectory-Based Operations (TBO) will allow the coordination of 4D trajectory predictions and constraints across all operational stakeholders improving throughput, flight efficiency and punctuality. However, we are some years away from such an ideal position.

A promising application of ML to improve prediction of take-off-times to enhance the accuracy of a ground based prediction of an aircraft's 4D trajectory (three spatial dimensions plus the time dimension) has been subject of a study by EUROCONTROL in collaboration with Thales in 2019.

At present, the most accurate Estimated Take-Off Time (ETOT) for each individual flight is provided by the Network Manager's Enhanced Traffic Flow Management System (ETFMS).

The ETFMS messages are sent to Air Navigation Service Providers (ANSPs) for flights entering their airspace and to Aircraft Operators (AOs) by the Network Manager Operations Centre (NMOC) each time there is an event triggering a recalculation of an aircraft's flight data.

In reality, aircraft do not always take-off according to the ETOTs reported by the ETFMS due to several reasons including congestion, bad weather conditions at the departure airport and reactionary delay. The ML prototype developed by EUROCONTROL takes into account several of these factors to improve the take-off time prediction of individual flights before their Estimated Off-Block Time (EOBT).

16. ENHANCED TBS WITH ML - SESAR/HEATHROW/NATS

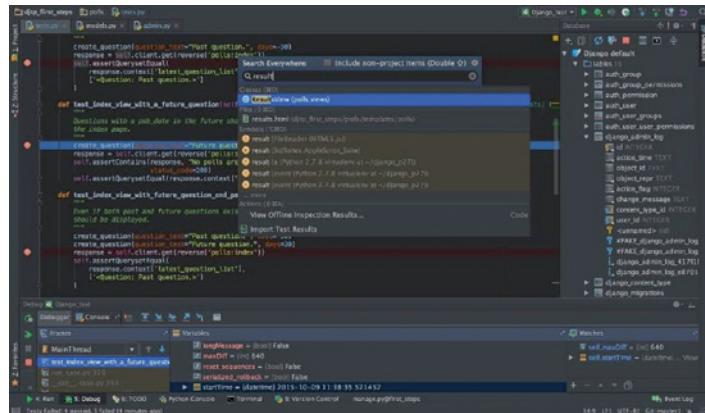
When there are strong headwinds, aircraft ground speed is reduced on final approach. This results in a reduced landing rate, causing delays and even flight cancellations. Already deployed at Heathrow, the TBS solution is undergoing further research within SESAR, including the use of machine learning to refine algorithms that define the wake separation minima, using prevailing winds data and downlinked aircraft approach data.

Heathrow Airport are trailing a number of use cases based on AI / ML algorithms, to be used in Operations.

One case is looking to at using a camera and AI to detect landing gear deployment points. The timestamped image of the moment the gear is fully down can be linked to a radar track and determine the distance from the airfield the gear was deployed. The gear detection system will be used to detect and promote best practice with regards to gear deployment. The later the gear is deployed, whilst remaining safe, the better the noise outcomes are for our local communities.

Another case is trailing the use of image recognition on the aircraft stands to detect and categorize Foreign Object Debris (FOD) prior to the arrival of the aircraft on stand. This can be integrated into safety alerts to the relevant staff which can take further action.

Finally, British Airways and Heathrow Airport are trailing the use of image recognition algorithms on turnarounds. A few cameras set up near the stand and on the boarding bridge capture images of the aircraft, and AI / ML algorithms detect various timestamps in the turnaround process, such as the moment when the re-fuelling truck arrives, when the boarding bridge has been connected etc. This can add an additional layer of detail and understanding of the turnaround process.



17. AUTOMATIC TAKE-OFF, TAXI AND LANDING – AIRBUS

Toulouse, 16 January 2020 – Airbus has successfully performed the first fully automatic vision-based take-off using an Airbus Family test aircraft.

Rather than relying on an Instrument Landing System (ILS), the existing ground equipment technology currently used by in-service passenger aircraft in airports around the world where the technology is present, this automatic take-off was enabled by image recognition technology installed directly on the aircraft.

Automatic take-off is an important milestone in Airbus' Autonomous Taxi, Take-Off & Landing (ATTOL) project. Launched in June 2018, ATTOL is one of the technological flight demonstrators being tested by Airbus in order to understand the impact of autonomy on aircraft. The next steps in the project will see automatic vision-based taxi and landing sequences taking place by mid-2020.

Airbus' mission is not to move ahead with autonomy as a target in itself, but instead to explore autonomous technologies alongside other innovations in areas such as materials, electrification and connectivity. By doing so, Airbus is able to analyse the potential of these technologies in addressing the key industrial challenges of tomorrow, including improving air traffic management, addressing pilot shortages and enhancing future operations. At the same time Airbus is leveraging these opportunities to further improve aircraft safety while ensuring today's unprecedented levels are maintained.



For autonomous technologies to improve flight operations and overall aircraft performance, pilots will remain at the heart of operations. Autonomous technologies are paramount to supporting pilots, enabling them to focus less on aircraft operation and more on strategic decision-making and mission management.

18. CYBER SITUATION AWARENESS IMPROVEMENT – EDA

The EDA Cat B project "Cyber Situation Awareness Package-rapid research prototype" (CySAP-RRP) aims at obtaining a common and standardized cyber defence planning and management functional area service. The objective is to provide commanders and other decision-makers with information to develop a clear understanding of the cyber-attack threat landscape. In order to do it, it has to equip them with the tools (competent personnel, effective procedures and technology platforms) to manage risks during the planning and conduct phases of a military operation. CySAP operates in full complementarity with a Security Operation Centre (SOC).

Current market available solutions for cyber situational awareness do not meet the entire spectrum of military requirements such as risk analysis, cyber related Courses of Action (CoA) development and assessment, as well as support to decision-making.

The application of AI is considered as one of the essential research challenges to assist military decision-makers in cyberspace and to set the basis for a fully-fledged Command and Control (C2) system for cyber operations. The use of AI will help to provide a comprehensive understanding of the cyber defence elements in the planning and conduct phase of military operations in which cyberspace is now recognised and treated as any other domain such as land, air or maritime.

Technology foresight activities will be concentrated on enhancing data processing techniques by using innovative knowledge, cognitive and learning systems. CySAP provides a situation analysis that can be integrated as Cyber contribution to an overall Common Operational Picture (COP). This allows for a meaningful representation of the information contributing to producing a timely and accurate situation awareness.

The project was conceived as the first step of a spiral development in order to set up a full Cyber Situation Awareness (CySA) operational capability. The results at the TRL 3-4 will be delivered using a spiral approach over 18 months (March 2019 – September 2020)

19. TCAS EVOLUTION (ACAS-X) – SESAR HONEYWELL

The SESAR Project TCAS Evolution - aimed at defining and assessing feasibility of ACAS evolutions required to support aircraft operations in the future SESAR environment. In this context it addressed the benefits associated with the implementation of extended hybrid surveillance capability into TCAS II in terms of reduced use of 1090 MHz frequency; development and validation of surveillance functions for a new generation of ACAS, referred as ACAS X; and performance study of new traffic awareness for collision avoidance systems designed for general aviation. The ACAS Xa concept, currently under definition within RTCA SC-147/ EUCOCAE WG-75, is being developed, optimized and validated through issuance of progressive versions of a collision avoidance system called "Runs". Project activities in this area consisted in continuous development of experimental platform, and fast-time simulation model allowing iterative evaluations of the system performance with focus given on surveillance functions. Three validations were performed within the scope of the project, with feedback being provided to standardization after each of them. Each validation was concluded by an update of surveillance technical specifications. Honeywell-developed experimental platform supported FAA ACAS Xa Run13 flight tests in 2015, and European Run14 real environment roof-top validation, as well as human-in-the-loop validation performed by DSNA and Airbus within SESAR context. This system uses heuristic rules to specify the best policies or actions to take to avoid collisions and maintain operational suitability for every state that the aircraft in the encounter could take on. While operating, the aircraft will estimate its current state and advice on the optimal actions. In several simulations and studies it has been shown that this form of AI/ML provides superior performance over other approaches, and has the best value of return for future conditions.

20. RUNWAY EXIT PREDICTION – H2020 SAFE CLOUD

SafeClouds has developed ML solutions for a variety of safety scenarios. The main objective of SafeClouds is information-driven analysis of hazard identification in aviation. This has required improving data management tools, including data decoding, formatting and cleaning. The team has developed an ad-hoc AI data platform, DataBeacon, a complete AI development cloud environment capable of scaling up as computational requirements grow, which allows data analysts to work more efficiently than before. DataBeacon provides analysts and data owners with Secure Data Frames (SDF) that allow accommodating data analysis needs with restrictions on privacy and confidentiality. This allows unprecedented use of large amounts of flight data, usually in the order of hundreds of thousands of flights. SDF approach means a great advantage compared to forcing data owners to release limited samples.

The unparalleled diversity of stakeholders, under a single AI effort, has allowed SafeClouds to be the first project to merge different data sources securely, supporting four safety scenarios that are not addressable without collaboration across aviation actors.



21. RPAS AUTONOMOUS CAPABILITY - EDA

The “Safe Autonomous Flight Termination (SAFE-Term)” is an EDA project targeting the development of RPAS autonomous capabilities to ensure a predictable yet adaptive RPA behaviour in case of emergency involving multiple failures, including C2 datalink loss, leading to a flight termination.

The project is also assessing the regulatory and certification issues and the standardisation needs related to this capability. These activities are particularly relevant for adaptative systems based on Artificial Intelligence, particularly when machine learning approaches are exploited due to the specific issues in the development, verification and validation processes of this technology.

The project focuses on situations where the RPA's airworthiness is compromised and the RPA needs to land as soon as possible in an emergency field or terminate its flight immediately. In this scope, the Specific Objectives (SO) of the project are to:

1. Assess different technological approaches for the implementation of autonomous capability for multiple failures leading to flight termination in C2 link loss. This includes:
 - a. Overall predictability of the RPA's response to a dynamic environment and the feasible approaches to communicate the RPA intentionality to the Air Traffic Controller Officer (ATCO) and other airspace users.
 - b. Autonomous detection of appropriate locations minimising the loss of life and property in case of emergency landing when the predefined emergency landing fields cannot be reached, and the use of novel approaches from adaptive systems development area (e.g. machine learning) to provide this functionality.
2. Assess the compliance of these technological approaches with current applicable certification standards in the aeronautical domain (e.g. ARP 4761, ARP 4754A...).
3. Select the most relevant implementation approach and development and validation of a proof of concept of this system.
4. Assess the potential enhancement to existing certification standards to accommodate the selected implementation approach and the way ahead to support the standardisation activities in this domain.

The project aims at reaching TRL 3-4 and entails two phases:

- Definition Phase devoted to the development of a Concept of Operations, a preliminary systems design and to assessing the standardisation and certification state of play. (September 2019-March 2020);
- Development Phase, in which a proof of concept of the system will be developed and validated in a simulation environment (April 2020 – March 2021).

22. VISUAL TRACKING IN DIGITAL TOWERS - EANS

The Estonian Air Navigation Services (EANS, trade name Lennuliikluseeninduse Aktsiaselts) decided to develop in-house remote tower technology in accordance with SESAR requirements and to build the first remote tower at the Tartu Airport site.

In case of remote tower, the services are provided remotely and the visual representation of the area of responsibility is received via aerodrome cameras, transferred via optical fiber cables and displayed on the panoramic screen at the working position called a remote tower module. Visual reproduction can be overlaid with information from additional sources, such as surveillance equipment. The visual reproduction will be enhanced with different technical solutions to support situational awareness in different light and visibility conditions. The technology is designed in such a way that there will be no need for major changes in operational working methods of air traffic services personnel.

The first step in the development of the remote tower technology was the design and construction of a remote tower prototype for Tartu Aerodrome by „shadowing“ the whole conventional tower equipment, except out-of-the-window view, which is now replaced with visual reproduction.

EANS remote tower system's visual presentation is captured by 16 cameras covering 360 degrees of the area of responsibility and displayed to 16 monitors with the size of 55". It also includes a pan and tilt zoom camera and signal light gun mounted on a pan-tilt device. The camera module is mounted on a frangible camera mast located on the top of Tartu Tower cab. The audio-video module with the ambient sound from the aerodrome is located on the ground floor of Tartu Airport Terminal. The videowall is overlaid with radar information allowing automatic radar tracking. The system also allows to automatically monitor the runway, change the camera settings in case of low or too intense light conditions, to rotate the videowall image in case of monitor failure and to add different overlays onto the videowall to improve the situational awareness. The whole system operations are recorded 24/7 and the recordings are stored for 30 days. The new version 2.0 of the system will include a long distance datalink, with full redundancy, integration of airport systems and VoiceCom, as well as a component of artificial intelligence: a visual tracking. Visual tracking means that the software will automatically recognise all the movements within the range of the remote tower cameras and will bring out all detected movements. AI will automatically recognize and classify whether the moving object is an aircraft, a person, a vehicle or wildlife. This functionality improves the situational awareness of the controller and facilitates the process of detecting relevant movements in the area of responsibility or near to the specified area. If the videowall of the remote tower doesn't cover 360 degrees totally, some objects or situations may not be taken into account because the controller doesn't have the view of the entire area of responsibility 24/7. In this case, the visual tracking brings the relevant movements out, alerts the controller and directs his/her attention to the respective area. This is an important safety feature that can help prevent incidents. It plays a crucial role in the multiple remote tower concept where controller's situational awareness is divided between several airports and constant overview is less than 360 degrees.

The development of a visual tracking has just begun. At this very moment input is being collected from Tartu aerodrome about different situations and objects that the software should be able to detect automatically. In AI terminology this process is called neural network training. The first live testing of the visual tracking is scheduled for early 2020. The system will be operational in 2021. Visual tracking will be implemented in all the four regional airports.

Above all the use of the visual tracking feature brings qualitative advantages. This functionality increases the controller's situational awareness as well as speeds up the process of detecting relevant movements in the area of responsibility. Visual tracking automatically moves the PTZ (pan-tilt-zoom) camera, which can increase the amount of serviceable traffic because you no longer need to manually find the object of interest and interact with the joystick. Therefore, this reduces the workload of controllers. In addition, it is an important safety element that can help prevent incidents.

23. INTUIT, DART, COPTRA, BIGDATA4ATM AND MALORCA PROJECTS – SESAR

Here are just a few examples of some of the complex problems where AI can lend support, addressing all phases of flight from strategic and pre-tactical planning to tactical de-confliction and operations themselves. These are already being explored today.

- **Strategic trajectory planning – INTUIT:** The project developed visual analytics and machine learning techniques to understand trade-offs between KPIs (safety, environment, capacity, efficiency).
- **Data driven trajectory prediction - DART and COPTRA:** these projects developed a trajectory prediction capability based on machine learning to estimate aircraft performance before or during the flight. Results are based on models previously trained with recorded trajectories.
- **Passengers behaviours' understanding - BigData4ATM:** The project investigated how different passenger-centric geolocated data can be analysed, to identify patterns in passenger behaviour, door-to-door travel times, and choices of travel mode. The aim is to enable optimised decision making for the benefit of passengers and goods, and improved ready times provided to the network for more predictable operations.
- **Speech recognition – MALORCA:** ATC instructions are for most of the time still given via VHF voice communication to the pilots. That means controllers making a lot of manual inputs to keep the system data correct. This is where automatic speech recognition can offer a viable alternative converting speech into text for input into the system.

The MALORCA project (Machine Learning of Speech Recognition Models for Controller Assistance) designed a versatile low-cost solution that adapts the speech recognition tools for use at any airport. The project ran between 2016 and 2018. In the initial phase, more than 100 hours of radar data and utterance from controller pilot communication for Vienna (LOWW) and for Prague (LKPR) airports approach areas were recorded. An initial basic ABSR was set-up for both Prague and also for Vienna. A command recognition rate of approximately 80% respectively 60% was achieved in the beginning. 25% of the remaining (untranscribed) data to improve the models through machine learning framework was then added at the first stage. The system performance has significantly increased. Another set of untranscribed data (to reach 50%, 75% and 100% of the total set) was then plugged in order to emulate the learning effect on monthly basis. Command recognition rates have eventually increased to 92% (Prague) and 83% (Vienna) respectively. The gradual improvement of recognition can be clearly visible from the figure below.

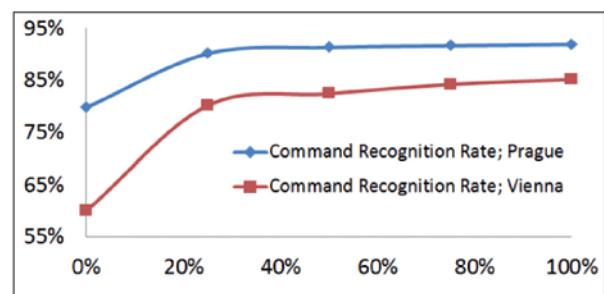


Figure 2 – Learning curve of command recognition for Prague and Vienna

MALORCA was a first demonstration of the potential of (semi) automatic adaption of controller assistance tools and proved for Prague and Vienna approach area that unsupervised machine learning is able to improve command recognition rate and that automatic learning from radar data and voice recordings can reduce costs of data, speeds up development and reduce manual adaptation effort. Furthermore, the conducted trials showed that recognition rates of machine learning trained system are high enough to reduce controller workload.

Research continues under the SESAR 2020 framework (project PJ.16-04).

24. THE DIGITAL SKY CHALLENGE

The Digital Sky Challenge took place in 2019 in Athens, It was a 48 hours Innovation Competition called a Hackathon. 56 participants working in 12 team located on the airside of the Athens Airports worked with 759 million records provided by 12 ATM data providers including EUROCONTROL, Aegean, Air France, Lufthansa, Aéroport de Paris, Fraport, Athens Airport, etc.

Participants had to design and implement creative products that would be judge on their innovation, business value, User experience and their technical feasibility. They needed data to start analysis current behaviours of passengers, airlines, airports or interaction between regulations, weather, flight path on disruption of operations.

The biggest challenge for organizers was to gather data and arrange legal aspects of the data sharing. The solution was found by the creation of a community where data providers could deliver their data. All operational data for Summer 2019 of provider were gathered for the creation of innovative solution for the ATM stakeholders. It was a wide scale and successful data exchange exercise.



LIST OF PARTICIPANTS

Christine Berg - DG MOVE
Leo Huberts - DG MOVE
Eric Perrin - DG MOVE
Nick Beresford - Heathrow Airport on behalf of ACI EUROPE
Daniel Turcu - Heathrow Airport on behalf of ACI EUROPE
Marc Lindike - Munich Airport on behalf of ACI EUROPE
Jean-Francois Ripoche - EDA
Ignacio Montiel Sanchez - EDA
Claudio Palestini – NATO
Ross Mckenzie - NATO
Ray Pinto - DIGITALEUROPE
Ignacio Baca - IFATCA
David Bowen - SJU
Marouan Chida- SJU
Stefano Prola - IATA
Houman Goudarzi - IATA
Benjamyn Scott - ASD
Frederic Sutter - AIRBUS – on behalf of ASD
Beatrice Pesquet-Popescu - THALES – on behalf of ASD
Joeri De Ruytter- Honeywell – on behalf of ASD
Eduardo Garcia - CANSO
Paul Bosman - EUROCONTROL
Sylvie Grand-Perret - EUROCONTROL
Franck Ballerini - EUROCONTROL
Sebastian Wangnick - EUROCONTROL
Benjamin Cramet - EUROCONTROL



EUROCONTROL

© March 2020 – European Organisation for the Safety of Air Navigation (EUROCONTROL)

This document is published by EUROCONTROL for information purposes. It may be copied in whole or in part, provided that EUROCONTROL is mentioned as the source and it is not used for commercial purposes (i.e. for financial gain). The information in this document may not be modified without prior written permission from EUROCONTROL.