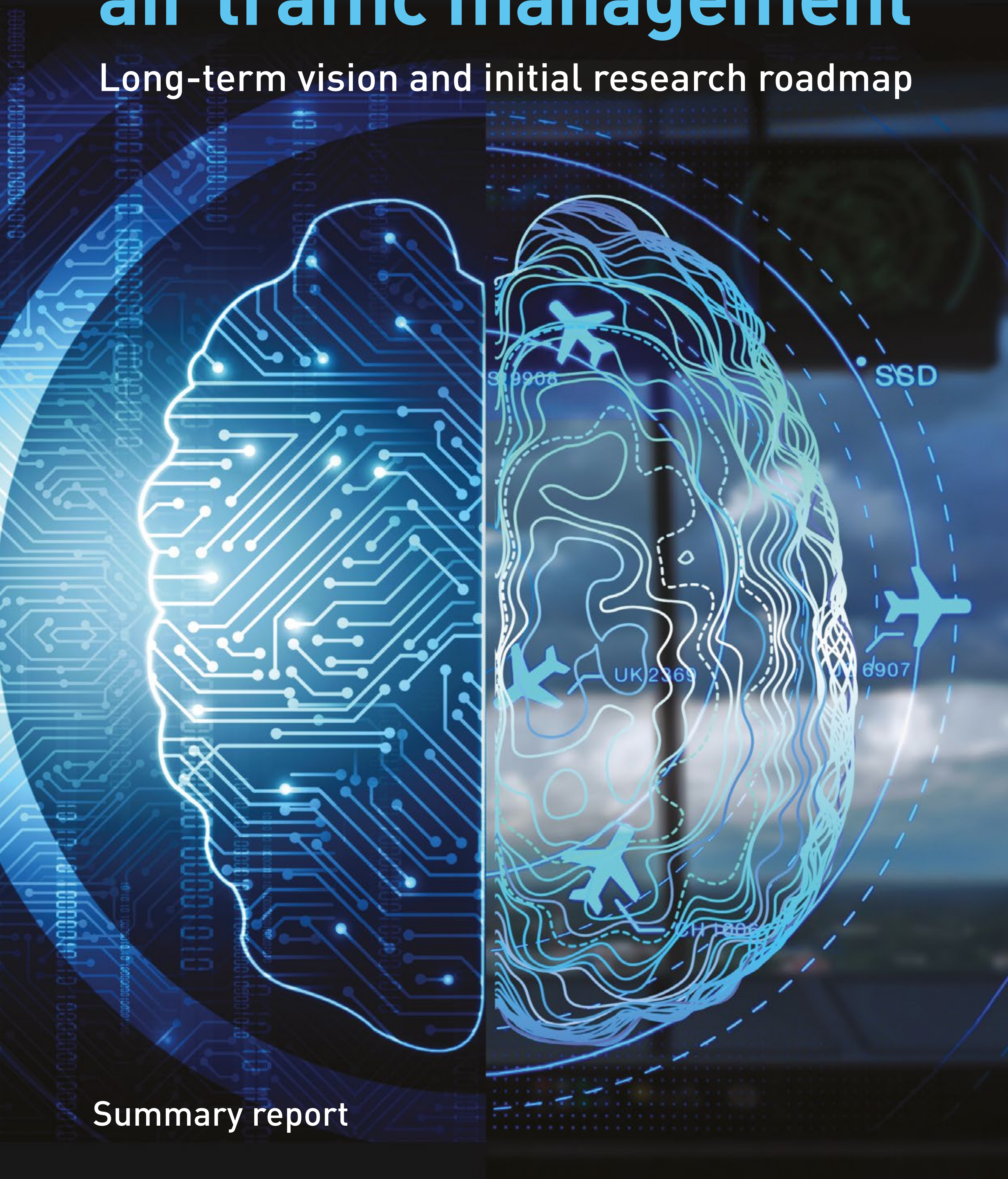
SESAR
JOINT UNDERTAKING

Automation in air traffic management

Long-term vision and initial research roadmap



Summary report

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Introduction

In 2019, the SESAR Joint Undertaking requested the SESAR 2020 Scientific Committee Automation Taskforce[1] to detail a long-term vision and research roadmap for automation in air traffic management (ATM), as a basis for the definition and coordination of future research activities. This document summarises a more extensive report on the topic, drafted by the Taskforce and submitted to the SESAR Joint Undertaking in September 2019.

Higher levels of automation supporting air traffic controllers' workload and reducing their stress are key for a future-proofed ATM system. This is in line with high-level documents paving the way for future research and deployment of ATM systems, such as the *European ATM Master Plan* [1], *Flightpath 2050* [2], the Advisory Council for Aviation Research and Innovation in Europe (ACARE) *Strategic Research and Innovation Agenda* [3], *Fly AI Report - Demystifying and Accelerating AI in Aviation/ATM* [4], the Association of European Research Establishments in Aeronautics (EREA) *From Air Transport System 2050 Vision to Planning for Research and Innovation* [5], the International Civil Aviation Organization (ICAO) *Global Air Navigation Plan* [6], the NextGen implementation plan [7], *Airspace Architecture Study* [8] or the NextGen–SESAR *State of Harmonisation Document* [9]. All these documents consider higher levels of automation to be central enablers for future ATM concepts.

The rise of new artificial intelligence/machine learning technologies provides opportunities for a fundamental change in the automation landscape. Artificial intelligence (AI), popularised in the 1950s, started with simple use cases employing handcrafted knowledge. Progressively, AI focused on so- called machine learning methods, based on exploitation of data-derived information instead of formalised human knowledge. While at first the success was limited due to insufficient data, the availability of many training exemplars (e.g. Big data resources) made possible the application of statistical-based deep-learning methods. While this has resulted in significantly increased performance in AI, it has come at a cost of reduced transparency and explainability, leading to understandable concerns about system validation and robustness. Table 1 summarises the main features of these first two waves of AI.

While other industries like the automotive industry have developed roadmaps [10], research in ATM automation currently lacks a long-term vision on automation. Although it is generally agreed that the future of the ATM system will evolve towards higher levels of automation, a shared vision is needed in order to develop a research roadmap with a breakdown of specific research actions.

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[1] SESAR JU Scientific Committee: https://www.sesarju.eu/discover-sesar/partnering-smarter-aviation/scientific-community

Table 1: Waves of AI, based on [11]

	First Wave	Second Wave	Second Wave ext.
Years	1960-1980	1980-2010	2010-
Technology	Expert-systems*	Machine learning	Deep learning
Algorithms	Logical rules	Statistical methods	Statistical methods
Expert knowledge	Expert knowledge ↓ Rules	Expert knowledge ↓ Model, Features	Expert knowledge ↓ Model
Learning		Parameters ↑ Data	Parameters ↑ Data
Algorithm application	Rules Data	Model ↓ Data	Model ↓ Data
Uncertainty handle	No	Yes	Yes
Abstraction	No	No	Yes
Interpretable	Yes	No	No

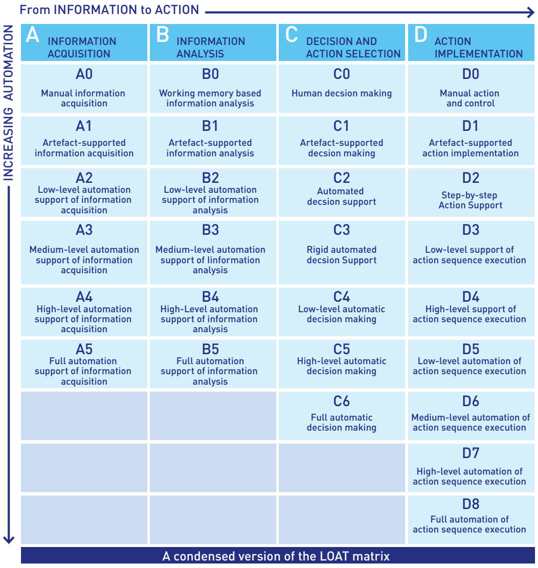
* It should be noted neural networks (and other forms of machine learning) started to be studied and used in the late 1950s, in parallel to expert systems development, although the later were prevalent in early successful AI applications.

Levels of automation in the SESAR research and innovation programme

The SESAR research and innovation programme (SESAR 1 and SESAR 2020) has featured many projects in the field of automation, resulting in a lot of ground-breaking and useful outcomes. An especially interesting paper [12] summarises the levels of automation taxonomy (LOAT, Figure 1) which were developed in SESAR [13], drawing upon aviation-related automation experiences. This LOAT was inspired by the renowned work from Parasuraman, Sheridan and Wickens [14].

Aligned with this taxonomy, the SESAR JU developed a simplified model on the levels of automation (LoA, Figure 2) specifically for audiences who are not necessarily experts in automation, which was published in the 2020 edition of the European ATM Master Plan [1]. This LoA model provides a simplified view of a long-term evolution towards higher automation levels and potentially full automation ("Controllerless"). The model illustrates how ATM and aviation will evolve into an integrated digital ecosystem characterised by distributed data services as envisioned in Phase D of the ATM Master Plan.

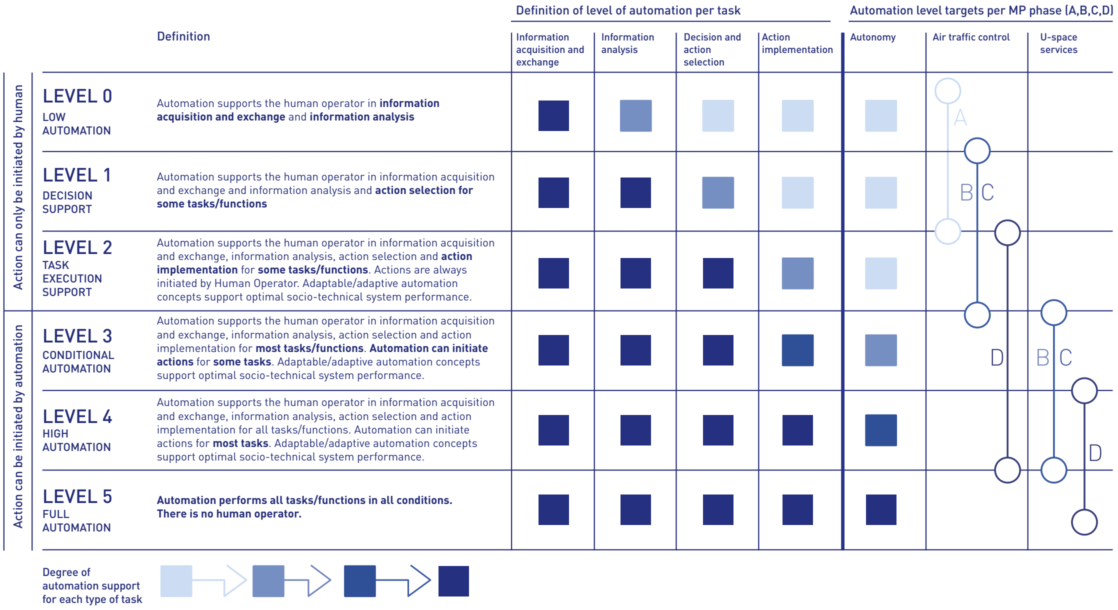
Figure 1: Levels of Automation Taxonomy (LOAT) based on [12] [13]



A INFORMATION ACQUISITION	B INFORMATION ANALYSIS	C DECISION AND ACTION SELECTION	D ACTION IMPLEMENTATION
A0 Manual information acquisition	B0 Working memory based information analysis	C0 Human decsion making	D0 Manual action and control
A1 Artefact-supported information acquisition	B1 Artefact-supported information analysis	C1 Artefact-supported decsion making	D1 Artefact-supported action implementation
A2 Low-level automation support of information acquisition	B2 Low-level automation support of information analysis	C2 Automated decsion support	D2 Step-by-step Action Support
A3 Medium-level automation support of information acquisition	B3 Medium-level automation support of linformation analysis	C3 Rigid automated decsion Support	D3 Low-level support of action sequence execution
A4 High-level automation support of information acquisition	B4 High-Level automation support of information analysis	C4 Low-level automatic decision making	D4 High-level support of action sequence execution
A5 Full automation support of information acquisition	B5 Full automation support of information analysis	C5 High-level automatic decision making	D5 Low-level automation of action sequence execution
		C6 Full automatic decision making	D6 Medium-level automation of action sequence execution
			D7 High-level automation of action sequence execution
			D8 Full automation of action sequence execution

A condensed version of the LOAT matrix

Figure 2: Levels of Automation [1]



		Definition	Information acquisition and exchange	Information analysis	Decision and action selection	Action implementation	Autonomy
Action can only be initiated by human	**LEVEL 0** LOW AUTOMATION	Automation supports the human operator in **information acquisition and exchange** and **information analysis**	█	▒	░	░	░
	LEVEL 1 DECISION SUPPORT	Automation supports the human operator in information acquisition and exchange and information analysis and **action selection for some tasks/functions**	█	█	▒	░	░
	LEVEL 2 TASK EXECUTION SUPPORT	Automation supports the human operator in information acquisition and exchange, information analysis, action selection and **action implementation** for **some tasks/functions**. Actions are always initiated by Human Operator. Adaptable/adaptive automation concepts support optimal socio-technical system performance.	█	█	█	▒	░
Action can be initiated by automation	**LEVEL 3** CONDITIONAL AUTOMATION	Automation supports the human operator in information acquisition and exchange, information analysis, action selection and action implementation for **most tasks/functions**. **Automation can initiate actions** for **some tasks**. Adaptable/adaptive automation concepts support optimal socio-technical system performance.	█	█	█	▓	▒
	LEVEL 4 HIGH AUTOMATION	Automation supports the human operator in information acquisition and exchange, information analysis, action selection and action implementation for all tasks/functions. Automation can initiate actions for **most tasks**. Adaptable/adaptive automation concepts support optimal socio-technical system performance.	█	█	█	█	▓
	LEVEL 5 FULL AUTOMATION	**Automation performs all tasks/functions in all conditions. There is no human operator.**	█	█	█	█	█

Degree of automation support for each type of task ░ → ▒ → ▓ → █

Long-term automation scenarios

The implementation of higher levels of automation imposes very demanding requirements not only on the technology itself, but it will also impact significantly the users and organisations, even at a societal level. Engagement with stakeholders and society, as well as those designing the system is needed in order to define a realistically acceptable proposal for the future of ATM automation. Table 2 shows a summary of the different challenges at each level. The three automation scenarios described in the table are suggested as potential candidates for a long-term vision of automation in ATM.

Figure 3: Summary of common automation challenges

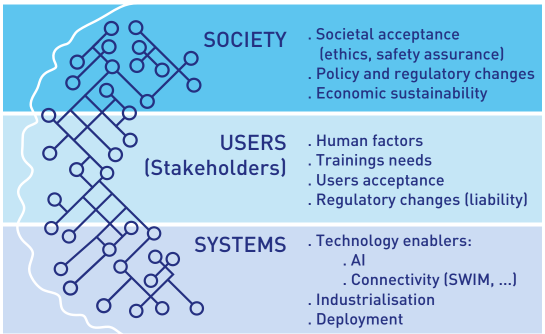
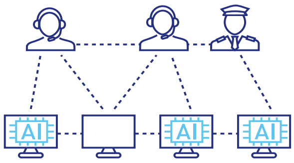
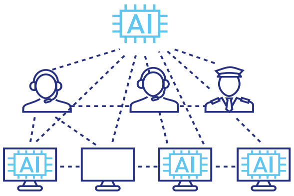
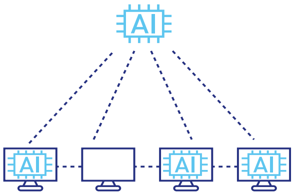


Table 2: Future automation scenarios as candidates for a long-term vision for automation in ATM

Scenario 1: Locally optimised ATM automation	Scenario 2: Holistic cognitive support	Scenario 3: Autonomous ATM
		
Key attributes • No major ATM functionality/role changes • Machine learning/AI solutions are embedded within the machine to support the human • Machine provides the human with enhanced situational awareness, decision support and action implementation tools to enhance productivity • Machine adapts to the human needs and mental state • Human keeps the central role in the ATM process as the only decision maker	**Key attributes** • Includes local optimisations from Scenario 1 • Human remains in control, most of the time decides and initiates actions • System can initiate and perform some actions, sometimes even overriding human actions • Human and the system are communicating via a multimodal user interface • System will continuously assess human belief state and predict human action • The automated machine to machine (M2M) interchange of information will result in improved coordination. • As the human remains a key element of the ATM system, the information flow rate needs to be adapted to human capabilities	**Key attributes** • Technical systems autonomously decide and execute actions, and all ATM functionalities are based on M2M interactions • Human performs a back-up role only • Pervasive use of big data enables AI/machine-learning applications to extract the necessary context information • A system mimicking the reasoning and behaviour of humans will help to address issues of transparency and user/societal acceptance • The automated M2M interchange of larger pieces of information will result in improved coordination • There is no need to adapt to human interaction capabilities anymore
Main opportunities • Increase overall system predictability, planning capability, "what-if" scenarios evaluation, by improving underlying support subsystems • Improve human-machine interface (HMI) and therefore reduce workload and stress • Improve human productivity and therefore reduce costs	**Main opportunities** • Improve prediction of ATM operations based on historical data • Improve human productivity and therefore reduce costs • Reduce human workload and stress as the system performs operations autonomously • Reduce human error by AI/machine learning systems acting as supervisor • Enable ATM (and flight deck) teamwork allocation changes	**Main opportunities** • No limitations related to human workload, higher potential scalability of the solution • Optimised operations due to the capability to interchange enriched information at a higher data rate • Operational cost reduction • No need to devote substantial research and development effort to HMIs, as the human is removed from the system
Associated automation levels EASA*: 1A-1B SJU**: 1-2	**Associated automation levels** EASA: 2A-2B SJU: 3-4	**Associated automation levels** EASA: 2B-3 SJU: 4-5

* As defined by EASA AI Taskforce

** As defined in the ATM Masterplan 2020.

Comparative analysis of scenarios

An assessment of the expected benefits and potential risks of the three scenarios by the SESAR Scientific Committee Automation Task Force is shown in Tables 3 and 4 below, where: VH = very high, H = high, M = medium, L = low and VL = very low; and S1 = Scenario 1, S2 = Scenario 2 and S3 = Scenario 3.

Additionally, these three scenarios were presented and evaluated during a workshop, which involved more than 40 participants representing each level (i.e. society, users, systems - see Figure 3) to get a holistic view on automation. The following conclusions can be drawn from the feedback received during the workshop.

Table 3: Expected benefits of future automation scenarios

	S1	S2	S3
Increased adaptability to context (improved generalisation)	M	H	VH
Capability to handle more complex tasks (involving multidimensional data)	VH	VH	H*
Reduce human stress, workload in nominal conditions (and as a result, increased capacity/reduced staffing costs)	M	M	VH
Reduce human stress, workload in non-nominal conditions (and consequently, increased safety)	M	H	VH**

* Not so clear, as we are losing human inherent resilience while being able to handle more computationally complex problems.

** Surely true in normal conditions but not necessarily under unexpected or safety-critical events. This is in fact a critical discussion point, as current ML and AI capabilities are unable to compete with human capability in handling non-nominal conditions being the human critical to maintain overall system resilience.

Table 4: Potential risks of future automation scenarios

	S1	S2	S3
Stability concerns (brittle system with erratic generalisation)	L	H	VH
Transparency concerns (reducing human situation awareness)	L	H	VL
Auditability concerns (complicating failure assessment)	L	H	VH
Lack of "creativity" when handling completely new circumstances	VL	L	VH
Reduction of human skills, which could be critical in failure situations (due to lack of training, experience, etc.)	L	H	VH
Lack of clearly established evaluation/validation procedures	H	VH	VH
User acceptance issues (trust, ethical issues, ...)	M	VH	VH
Legal issues (lack of clarity in liability)	H	VH	VH
Society acceptance issues	VL	M	VH
Risks related to unintended system manipulation (cyberattacks, ...)	L	H	VH

Human advantage vs limitations: While the first two scenarios are human centric, the human is removed from the systems in the autonomous scenario (S3). As a result, the autonomous scenario does not offer human resilience and capabilities to solve problems present in the current ATM system. On the other hand, the scenario is not restricted by human performance limitations. However, also the capability to detect and refuse hazardous human actions and workload management functions in the holistic scenario can help to alleviate the problem of human limitations.

Evolutionary vs revolutionary approach: The first two scenarios were considered feasible as they are evolutions of the current system, while the disruptive approach of the autonomous scenario (S3) was considered too risky.

Performance: there is a general consensus that local optimised ATM scenario (S1) will be unable to cope with future traffic increases as it only foresees minor refinements to the current system. The two other scenarios are expected to be able to handle the expected increase in traffic demand.

Interoperability: Both holistic (S1) and autonomous (S2) scenarios could result into interoperability improvements if standardisation and stakeholder involvement is achieved.

Costs: It is important to consider not only staffing costs but also costs related to maintenance, research and deployment – which will be prevalent in the autonomous scenario (S3). However, an in-depth costs assessment is out of scope of this report.

Use of unmanned traffic management (UTM)/ U-space[2] innovation: The autonomous scenario can benefit from current research on and implementation of U-space. U-space foresees the introduction of high levels of automation and the integration of machine learning/AI-based solutions in drones and ground systems, which may lead to solutions that could be potentially applied to the ATM system.

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[2] U-space is a set of new services and specific procedures designed to support safe, efficient and secure access to airspace for large numbers of drones.

Conclusion and initial roadmap

Based on the taskforce's analysis and feedback from the workshop, the "holistic cognitive support" scenario (S2) should be pursued in the mid (2035) to long-term (2050) future. With this scenario, the vision of the future ATM system remains resolutely human-centric but at the same time, the technical system gains a certain level of autonomy. Both the operator and the system work in close cooperation maintaining a multimodal conversation and making use of the most recent advances in AI/machine learning. As ATM is a distributed socio-technical system of systems, new challenges may arise with the introduction of decentralised AI/machine learning. Work will be required in several key areas, such as an analysis of emergent behaviour, the development of design guidelines to guarantee a robust performance while dealing with uncertainty, new approaches to evaluation and validation, and addressing task allocation in teams, layers and systems.

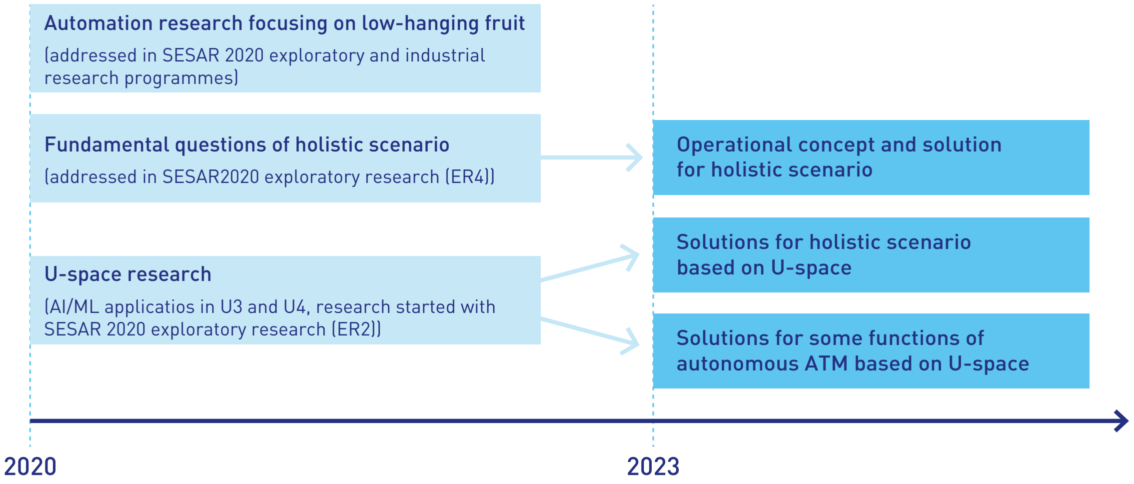
Although the vision of a fully autonomous solution is currently not supported, U-space research on higher levels of automation and full automation in safety critical tasks may have the potential for a transfer or adaptation to ATM.

Based on the abovementioned issues and the discussions at the workshop, the following initial roadmap illustrated in Figure 4 is recommended.

In the short term, a speedy implementation of AI/machine learning solutions, as outlined in the "local optimised ATM" scenario (S1), should continue in order to realise short-term performance improvements. At the same time, research should continue to address fundamental questions related "holistic cognitive support" scenario (S2) - This work is currently being performed in SESAR 2020 industrial and exploratory research strands. U-space research should continue in parallel, in particular on applications of AI/ML according to the U-space research roadmap outlined in the U-space Blueprint [15].

In the medium term (2023-2025), ATM automation research should start to investigate and mature the first applications of the "holistic cognitive support" scenario (S2). Additionally, U-space results should be analysed to assess the feasibility to transfer solutions for the holistic scenario to ATM. The transfer of U-space solutions offering full automation could be also investigated for some functions of the ATM system.

Figure 4: Initial automation research roadmap



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