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Abstract

This document establishes the initial work carried out in the project, focused on:

- The definition of the future role of the ATCO for relevant themes touched within the project
- The overview of the solution underlining benefits and objectives related to it, as well as which stakeholders are impacted by the systems and why. Moreover, a functional view of the system is provided, focusing on the interactions between capability configurations and their functional decomposition.
- The detailed description of the functional requirements for the relevant themes and its assumptions.

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Authoring & approval

Author(s) of the document

Organisation name	Date
DBL	01/11/2023
ENAC	01/11/2023
CRIDA	01/11/2023
NLR	01/11/2023
ECTL	06/12/2023

Reviewed by

Organisation name	Date
ENAC	15/12/2023
BS	15/12/2023
CRIDA	15/12/2023
UPM	15/12/2023
NLR	15/12/2023
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Approved for submission to the SESAR 3 JU by[1]

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DBL	20/12/2023
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UPM	20/12/2023
NLR	20/12/2023

[1] Representatives of all the beneficiaries involved in the project

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Copyright statement

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CODA

Controller Adaptive Digital Assistant

CODA

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1 Executive summary

The overall objective of the CODA project is **to increase ATM's efficiency, capacity, and safety**, maximising human-AI teaming by developing a system in which tasks are performed collaboratively by hybrid human-machine teams and dynamically allocated through adaptive automation principles. To do so CODA focus on developing a solution that predict relevant mental states of en-route air traffic controllers so to anticipate possible problems and trigger specific actions (such as the activation of Digital Assistants). The improvements proposed by the CODA project will impact the Air Traffic Controllers (ATCOs) work in an **en-route sector with a congested traffic situation environment.**

The solution could enable some changes in tasks and roles of ATCOs. The **future role of ATCOs and the context related to them** is investigated as one of the objectives of the study, but not strictly defined, as this will be highly impacted by the technical environment that will be available in the future (e.g. highly automated tools, AI digital assistants). Our work focuses on the changes in the AI domain, how data will be shared, planning and monitoring activities, remote working, standardisation between sectors, continuous monitoring by systems, differences between ATCOs roles, ATCO-supporting tools and adaptive interfaces. A visionary outlook for air traffic control is investigated and presented, envisioning a significant transformation driven by AI integration. It forecasts the evolution of ATCO roles toward strategic planning and supervision, facilitated by AI's support in routine tasks. Emphasizing data sharing, advanced tools, and adaptive interfaces, it underscores safety, efficiency, and collaborative decision-making. However, challenges like trust in AI, competency shifts, and system resilience are acknowledged as crucial areas for attention in this forward-looking perspective.

The solution involves integrating Artificial Intelligence (AI) into Air Traffic Management (ATM) to overcome current limitations. AI aids in decision-making, pattern identification, and optimization, but requires transparency in its reasoning for Human-AI Teaming. The system aims to integrate AI tools, predicting and preventing issues, enhancing operator performance, and maintaining safety. It focuses on real-time decision support, safety measures, operational efficiency, human-AI collaboration, and adaptability. Stakeholders impacted include academia, regulatory bodies, industry, operators, and the public.

Moreover, a **functional view of the system** is provided, focusing on the interactions between capability configurations and their functional decomposition. The functional view details interactions between various systems, emphasizing decision support, safety, efficiency, human-AI collaboration, scalability, and adaptability. The solution decomposes into five key capability configurations with roles and technical systems. It impacts the baseline SESAR architecture by enhancing technical systems, evolving functions, adapting roles, and requiring increased scalability, adaptability, and collaboration.

The CODA project will start with a TRL (Technology Readiness Level) 1, and it sets the goal of achieving a **TRL 2** by the end of the work. The CODA solution is **an enabler for adapting systems** based on AI tools and other types of automation. Once the feasibility of the concept is confirmed within the current project, further steps would be: i) to Investigate the use of the system also in other relevant use cases (such as Tower controllers, TMA controllers) ii) to assess the precise impact on KPIs once the system is actually connected to Digital Assistants (out of scope for this project).

2 Introduction

2.1 Purpose of the document

This document provides the future roles and contexts of Air Traffic Controllers (ATCOs) at high level. It involves compiling anticipated changes in the role of ATCOs. Futures technologies which (may) impact these future roles are described based on literature surveys, the consortium's knowledge and workshops with End Users (ATCOs). Future technologies, roles and contexts which need to be covered in terms of functional requirements are covered at high level. Functional requirements which are not applicable to the CODA solution are kept for future reference, clearly described as not applicable. The ATCOs' future roles and functional requirements are described based on eight topics:

- Artificial intelligence (AI)
- Sharing of data with a wider group of stakeholders
- Planning and monitoring rather than active controlling
- More standardisation between sectors, towers, CWPs
- Being monitored continuously by systems
- Differences between different ATCOs roles
- ATCO-supporting tools
- Adaptive interfaces

This document defines the functional requirements for the CODA solution at TRL2.

2.2 Scope

As stated above, the purpose of this document is to present the CODA Functional Requirement Document (FRD) and to provide the result related to the third task of the **WP2 - Adaptive automation state of the art and use cases definition**, namely T2.3 ATCO Future Roles.

The work contained in this deliverable is closely linked to the deliverable D2.2 OSED, which not only includes the OSED but also the current state of the art on ATCO roles and contexts and definition of generic use cases.

The end product will be new futuristic tools, technologies and operational concepts with adaptive (AI-based) components which will form the base for the developments in the following CODA work packages. FRD – Functional Requirements Document details the CODA system functional description and the necessary logical interfaces with other systems, covering functional and interface requirements.

2.3 Intended readership

The intended audience for this document primarily consists of all the partners involved in the CODA project.

External to the SESAR project, other stakeholders are to be found among:

- ATM Stakeholders:
  - ANSPs (Air Navigation Service Providers)
  - ATM infrastructure and equipment suppliers
  - Airspace users
  - Airport owners/providers
  - Affected National Supervisory Authorities (NSA)

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- Affected staff organisations
- Air Traffic Controllers (ATCOs)
- Regulatory and standard organisations:
  - EASA
  - ICAO
  - European ATM Standards Coordination Group (EASCG)
  - EUROCAE
- Other Single European Sky ATM Research (SESAR) solutions partners.

2.4 Background

The CODA project aims to demonstrate the feasibility of developing a system in which tasks are collaboratively performed by hybrid human-machine teams and dynamically allocated through adaptive automation principles.

To achieve this goal, the project consolidates the work previously undertaken in the following SESAR Exploratory Research projects:

- The findings from ARTIMATION and MAHALO will be utilized to develop an AI-based adaptable and explainable system, allowing the system to proactively prevent future performance or safety issues.
- The outcomes of MINIMA and STRESS will be employed for a neurophysiological assessment of mental states. This will enable the system to discern operators' real-time levels of workload, attention, stress, fatigue, and situation awareness.
- The results from COTTON and eCOMMET will contribute to the development of prediction models, anticipating future situations. This enables the system to understand which activities will be undertaken by operators in the future and their potential impact on human factors.

2.5 Structure of the document

This document has the following structure:

Chapter 1 (Executive summary): contains a brief description of the document.

Chapter 2 (Introduction): contains the purpose, the scope, the intended readership, the background, and the structure of this document. Further significant information such as glossary of terms and list of abbreviations have been included at the end of the chapter.

Chapter 3 (ATCO future roles and contexts): describes how the future role of ATCOs and the context related to them will change. It focuses on the changes in the AI domain, how data will be shared, planning and monitoring activities, remote working, standardisation between sectors, continuous monitoring by systems, differences between ATCOs roles, ATCO-supporting tools and adaptive interfaces.

Chapter 4 (Functional architecture view): describes the overview of the solution underlining benefits and objectives related to it, as well as which stakeholders are impacted by the systems and why. Moreover, a functional view of the system is provided, focusing on the interactions between capability configurations and their functional decomposition.

Chapter 5 (Functional requirements): presents the functional requirements related to topic illustrated in Chapter 3, namely the ones that potentially impact ATCO future role and activities.

Chapter 6 (Assumptions): outlines a set of general and specific assumptions that will be considered in the CODA project.

Chapter 7 (References): the references, and applicable documents.

2.6 Glossary of terms

Term	Definition	Source of the definition
Air Traffic	All aircraft in flight or operating on the manoeuvring area of an aerodrome.	ICAO Annex 11 - ATS
Air Traffic Controller	• Qualified in accordance with ICAO Annex 1 – Personnel Licensing and holding a rating appropriate to the assigned functions, • A person authorized to provide air traffic control services.	EUROCONTROL ATM Lexicon
Air Traffic Management	The dynamic, integrated management of air traffic and airspace including air traffic services, airspace management and air traffic flow management – safely, economically and sufficiently – through the provision of facilities and seamless services in collaboration with all parties and involving airborne and ground-based functions.	ICAO 4444 - ATM
Air Traffic Services	A generic term meaning variously, Flight Information Service (FIS), Alerting Service (ALRS) and Air Traffic Control Service (ATC) (area control service, approach control service or aerodrome control service). In this document, when the term ATS is used, it is usually referring to TWR or AFIS.	ICAO, Annex 11
Sector	A part of a control area and/or part of a flight information region or upper region.	EU 2015/340

Table 1: Glossary of terms

2.7 List of acronyms

Term	Definition
ALARM	multi-hAzard monitoring and earLy wARning systeM
ADP	Adaptive Interfaces
AI	Artificial Intelligence
AISA	AI Situational Awareness Foundation for Advancing Automation
ANSPs	Air Navigation Service Providers
ARTIMATION	Transparent Artificial Intelligence and Automation to ATM Systems
ATCO	Air Traffic Controller
ATCS	Air Traffic Control System
AST	ATCO Supporting Tool
ATM	Air traffic management

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ATS	Air traffic services
CD&R	Conflict Detection & Rresolution
CODA	Controller Adaptive Digital Assistant
COTTON	Capacity Optimisation for Trajectory Based Operations
CTO/CTA	CTO/CTA: Controlled Time Over/At.
CWPs	Controller Working Positions
DES	Digital European Sky
DIF	Difference
EASA	European Union Aviation Safety Agency
eCOMMET	Cognitive Complexity Tool
EPP	Extended Projected Profile
FRD	Functional requirements document
GA	Grant agreement
HAAWAII	Highly Automated Air Traffic Controller Workstations with Artificial Intelligence Integration
HE	Horizon Europe
ID	Identifier
LTM	Local Traffic Management
MAHALO	Modern ATM via Human/Automation Learning Optimisation
MET	Meteorology
MINIMA	MItigating. Negative Impacts of Monitoring high levels of. Automation
NLP	Natural Language Processing
NM	Nautical Mile
OSED	Operational service and environment description
PAM	Planning and Monitoring
RBT	Reference Business Trajectory
REDA	Readback Error Detection Assistant
SA	Situation Awareness
SESAR	Single European sky ATM research
SESAR 3 JU	SESAR 3 Joint Undertaking
SOD	Sharing of Data
SPO	Single Pilot Operations
SRIA	Strategic research and innovation agenda
STD	Standardisation
STRESS	Human Performance neurometricS Toolbox foR highly automatEd Systems deSign
TAPAS	Towards an Automated and exPlainable ATM System
TRL	Technology Readiness Level
UTM	Unmanned Traffic Management
XAI	Explainable AI

Table 2: List of acronyms

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3 Future roles and contexts

Within this Chapter, the future roles and contexts of ATCOs are described at high level based on the results from literature surveys, consortium's knowledge and the two workshops with End Users (ATCOs) and ATC CWP equipment manufacturers. It involves compiling anticipated changes in the role of ATCOs. During the workshops, futuristic scenarios were discussed, evaluating their advantages, drawbacks and conditions/assumptions for realization. The end product is new futuristic tools, technologies and operational concepts with adaptable (AI-based) components which will form the base for the developments in the following CODA work packages.

The following paragraphs within this Chapter describe the results from literature surveys, consortium's knowledge and workshops on a high level. Each paragraph is related to a future change (potentially) impacting ATCO future roles:

- Artificial intelligence (AI) wide usage,
- Sharing of data with a wider group of stakeholders,
- Planning and monitoring rather than active controlling,
- More standardisation between sectors, towers, CWPs,
- Being monitored continuously by systems,
- Differences between different ATCOs roles,
- ATCO-supporting tools,
- Adaptive interfaces.

3.1 Artificial Intelligence

The increasing level of automation has been part of the SESAR roadmap since the beginning of the programme and a recurring topic with emphasis on the question about the optimum level of automation considering the human operators and looking for the optimisation of the cognitive system formed by the automation and the operator [7]. The advance in the Artificial Intelligence, AI, and its possibilities has fostered this debate which nevertheless has continued maintaining the human in the centre, requesting some characteristics from the AI with highlight of transparency, explainability, conformance, situation awareness and trust [8].

As stated by some ATCOs within project workshop, there is debate if the introduction of AI would lead to a disruptive change in ATM, likewise the introduction of radar technology. The tasks foreseen where AI can support ATM are broad and cover all the phases from strategic planning to separation assurance: by supporting the optimum airspace design for dynamic airspace to post-operations analysis with the identification of patterns in air traffic and demand, or as CODA proposes, teaming with the controller to support the optimum performance considering the works that needs to be done and the mental state of the operator.

The projects developed within SESAR that address the future of AI in ATM (Aisa, Aritmation, Mahalo, Safeops, and Tapas) have obtained a set of needs that AI should fulfil. These conclusions are described in the joint white paper [8] and summarized in the paragraphs below.

Explainability/transparency. The need of an explanation behind the solution proposed by AI depends on several factors, the main ones being the available time and the experience of the human operator. While in the training phase or novice controllers will further explore the reasoning behind a proposal, and thus gain trust in the system, during execution or experienced controllers demand less explanations. The possibility to provide further information on demand is thus one of the needs of the future AI.

Personalisation/ conformance. Understanding and acceptance of the AI solutions can be achieved through personalization of the AI. Developing trust and confidence can be achieved providing reliable solutions, but they can be lost very rapidly and rebuilding them can be hard. Personalization (to support acceptance) and reliability of the explanations and solutions are another of the needs of the future AI.

Stakeholder and field experts' involvement. Using a user-centric approach to develop the systems ensures that relevant feedback is obtained since the early states of the AI exploitation and increases the acceptance of the developed solution.

Safety assessment. Including AI failure modes in the system safety assessment or developing AI performance metrics would allow the detection of false predictions and thus wrong support.

Learning Assurance. AI predictions are highly dependent on the data sets used to create them. Quality and validated data sets are key to build an AI solution that correctly identifies the data patterns and therefore proposes the optimum solution.

3.2 Sharing of data with a wider group of stakeholders

The concept of human-AI teaming holds the potential to revolutionise the world of Air Traffic Management (ATM), introducing a new approach to collaboration where data plays a key role in facilitating collective decision-making. This literature review explores the anticipated types of data that will be shared between ATCOs and various stakeholders, alongside the communication channels envisaged for this symbiotic collaboration, emphasizing its significance in the evolution of air traffic management.

Data exchange to improve performance and safety: In the future of Air Traffic Management, data exchange is expected to play a pivotal role in improving performance (e.g., increased level of SA distributed among aviation stakeholders [16]) and safety. The evolution of technology, increased connectivity, and advanced data analytics will contribute to a more efficient and secure air traffic management system, with the contribution of elements such as:

- **Real-Time Aircraft Data sharing:** Predictive analytics and machine learning will help the ATCO anticipate traffic patterns and weather events, enabling proactive decision-making. While predictive models analyse historical and real-time data to foresee traffic flows and weather conditions, machine learning processes vast datasets for dynamic decision-making and optimizing airspace utilization. This will enhance adaptability, optimise resources, and enhanced safety for a more agile and effective aviation management system [17].
- **Adaptive Interoperability:** Pilots, flight crews, and ground crews will engage in data sharing to address operational challenges and share strategies for improved safety and efficiency. This includes sharing insights into weather conditions, mechanical issues, and operational challenges [18] and it will be done through the integration with evolving technologies. The ATC system will seamlessly integrate with evolving technologies, ensuring adaptability to new tools and systems. This adaptive interoperability enhances efficiency amid ongoing advancements and a growing network of industry stakeholders.

Several types of data could be shared:

- Real-Time Aircraft Trajectories
- Operational Insights (e.g. Pilots, flight crews, and ground crews -> weather conditions, mechanical issues, and operational challenges)
- Cyber Threat Intelligence (e.g. sharing information on identified cyber threats)

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- Data for Shared Situational Awareness (e.g. shared understanding of the operational environment among all involved stakeholders, e.g. airports, airlines, ANSPs)
- AI-Generated Insights (e.g. predictive maintenance, route optimization, decision making, and overall operational efficiency)
- Safety Management System (SMS) Data

Systems like CODA would add to the set of data that could be shared also **the ones related to operators' mental states and the solutions activated by the system**.

Challenges

As the world of aviation moves into a future where technology plays a more prominent role, the shared exchange of diverse data types between ATCOs and stakeholders, facilitated by Artificial Intelligence, is the cornerstone of progress. However, it's essential to know that some challenges must be addressed.

- **Cybersecurity:** it will be essential to have proactive Cybersecurity Measures to anticipate and address cyber threats to ensure data integrity and confidentiality. Proactive cybersecurity measures will fortify infrastructure against emerging risks, safeguarding critical information from unauthorised access and breaches.
- **Compliance with Privacy Regulations**: Ensuring compliance with privacy regulations requires strict adherence to emerging privacy standards. This will be vital for safeguarding the privacy rights of individuals and ATM organizations. Prioritizing data protection will establish trust and meet regulatory expectations, protecting against potential legal and ethical challenges from privacy breaches.
- **Data Resilience and Sustainability:** Focusing on data resilience will be crucial for adapting to increasing data volume, ensuring operational continuity, and mitigating risks in the Air Traffic Control system. Enhancing overall reliability will make the system robust in a dynamic aviation landscape.

Expected benefits and limitations

From the user's perspective, as investigated during a dedicated workshop with ATCCOs representatives, the main expected benefits of improved data exchange among all ATM stakeholders are summarised below:

- Increased accuracy of predictions.
- Stakeholders' needs could be shared and more effectively addressed. Also requests and decisions taken by the single actors would be easier to understand.
- More data available to Improve the training of AI/ML systems, as well as their test and validation.
- Improved predictability, short and long time
- Sharing of knowledge and best practices between disciplines, including ATM
- All the performance indicators can be positively impacted.

Some possible issues identified by users are:

- Fragmentation of ANSPs sovereignty issues
- Different Air Navigation Service Providers (ANSPs) present different data features
- Reluctance to share data
- Security
- System non-interoperability.

3.3 Planning and monitoring rather than active controlling

As AI continues to permeate the aviation landscape, the role of air traffic controllers (ATCOs) is about to undergo a significant shift from active control to planning and monitoring. Whereas traditionally, ATCOs have been responsible for direct control of aircraft movements, issuing clearances, managing traffic flows and ensuring safe separation, the increasing complexity of airspace requires a more strategic approach. Indeed, with the increasing volume, density and heterogeneity of air traffic, traditional methods of manual control are becoming increasingly strained. AI can provide real-time insights and predictive analysis, complementing human expertise and enabling ATCOs to effectively manage complex airspace environments. AI can **automate many of the repetitive** and time-consuming tasks currently handled by ATCOs, such as tracking aircraft positions, issuing clearances, initiating aircraft transfers across sectors, and monitoring weather conditions. This automation frees up **ATCOs to focus on higher-level strategic planning** and decision-making. In terms of Human Factors, by automating many of the routine tasks, AI can help to reduce the workload and stress of air traffic controllers and by involving them in more strategic tasks, AI might increase ATCOs' job satisfaction, with jobs considered more rewarding and challenging. AI algorithms can analyze vast amounts of data to identify potential conflicts and hazards, allowing an extension of the time horizon, reducing trajectories uncertainties and enabling early planning and monitoring of traffic flows. The switch from active control to planning and monitoring should enable to streamline traffic flows, reduce delays, and improve overall airspace utilization. This can lead to significant cost savings for airlines and passengers alike.

In the AI-driven ATM landscape, the role of ATCOs will evolve towards a more strategic and supervisory stance. ATCOs will transition from hands-on, direct control to a more planning- and monitoring-oriented approach. Their responsibilities will encompass:

- Strategic Planning: ATCOs will utilize AI-generated insights to develop long-term traffic flow plans, optimize airspace usage, and anticipate potential issues.
- Real-time Monitoring: ATCOs will continuously monitor air traffic using AI-powered surveillance systems, identifying potential conflicts and hazards at a wider time horizon, and taking corrective actions when necessary.
- Decision-making Support: AI will provide real-time decision-support tools, advising ATCOs on course corrections, altitude changes, and other measures to maintain safety and efficiency.
- Control by exception: While AI-based prediction tools will support the traffic smoothing and the definition of conflict-free trajectories, the ATCOs are expected to intervene by exception to handle the unexpected situations (e.g. emergency, weather events).
- Human Oversight: ATCOs will retain ultimate decision-making authority, ensuring that human judgment and expertise remain paramount in air traffic management.

Of course, there are also some challenges associated with this shift. For example, air traffic controllers need to be able to trust AI systems and to understand how they work in order to use them effectively. Additionally, there is a risk that AI could become too autonomous, which could lead to a loss of human control over air traffic management. A smooth transition to a more AI-assisted working environment for ATCOs requires a comprehensive approach that addresses technological, organizational, and human factors.

Human factors considerations shall address potential human factors issues, such as **workload** management, bias mitigation, **trust** in AI and cultural adaptation, loss of motivation [24, 25, 26]. Human-AI collaboration needs to rely on the complementary nature of human and AI expertise, AI augmenting ATCOs' capabilities by providing data insights, automating routine tasks, and identifying potential conflicts. ATCOs, with their experience and judgment, can make informed decisions based on AI recommendations, particularly in non-nominal situations. ATCOs need to trust and understand AI recommendations, while AI should be designed to complement human expertise, not replace it. Roles and responsibilities shall be clearly defined. Although less involved in active control, more **controlling "by exception"**, ATCOs should retain ultimate control over air traffic management decisions, while AI serves as a supportive tool. This clear distinction prevents potential confusion or overreliance on AI. Appropriate training shall provide ATCOs with the necessary skills and knowledge to work effectively with AI, covering AI principles, applications, limitations, and ethical considerations. Establishing a robust regulatory framework is necessary to ensure the responsible and safe integration of AI into ATM aligned with the new planning and monitoring roles of ATCOs. This framework should address safety, data privacy, and ethical concerns. To ensure the accuracy and reliability of AI systems, as well as to maintain optimal performance, AI models, algorithms and outputs shall be continuously monitored and assessed.

As mentioned during the users' workshop, the shift from active control to planning and monitoring in can have both positive and negative implications in terms of resilience. The ATM system is expected to be less prone to failures and human errors due to reduced workload, enhanced situation awareness and improved decision-making. However, the system is facing challenges and resilience costs.

- First, beyond the reduced opportunities to actively control aircraft, there is a risk of **overreliance on AI systems**, which may lead to a potential loss of manual control skills among air traffic controllers. If the AI system fails or encounters a situation it is not designed for, controllers might face challenges in taking back immediate control.
- Second, AI systems, while excellent at handling routine scenarios, might struggle with novel or unexpected situations and **fail to adapt to unforeseen events**. Air traffic controllers need to be agile and smart in adapting to unforeseen events, especially if the AI system encountered challenges. The major risk associated with this leftover strategy (i.e. the human in charge of handling remaining situations left over by the AI) is that it might be simply not be feasible as the AI will allow an increase in traffic which in an emergency situation or a failure of the AI will overburden the human in the system.
- Third, introducing AI increases system wide dependency, with the answer to an AI failure being in the beginning at least to close the airspace. The disruption potential is much higher when the digitalisation is introduced into ATM. Currently the redundancy is an integral part of the system functionality, whereas in the future this might be lost, or a particular attention would need to be created to address it.

The transition to a more supervisory role requires controllers to undergo **training** not only **to understand and effectively utilize AI systems** but also to **detect and handle** situations when the AI encounters such challenges. The learning curve and the time required for controllers to become proficient with the new tools can pose challenges. While AI can enhance ATCOs' building and usage of situational awareness[3], there is a need to ensure that controllers **remain actively engaged** in the system's outputs and maintaining overall situation awareness and control, even in a

[3] AI can enhance ATCO's building and usage of situational awareness through enhancing display of relevant information (perception), enhancing the explainability/understandability of the situation (comprehension), and providing support to predict how the situation might evolve, e.g. what-if (projection)

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more supervisory role. Last of all, increased reliance on AI introduces new cybersecurity risks. Ensuring the resilience of AI systems against cyber threats is crucial to maintain the integrity and safety of air traffic control operations.

3.4 Standardisation between sectors, towers and/or CWPs

In this fast-evolving landscape of civil aviation, the push towards standardization, particularly in integrating future technologies at Controller Working Positions (CWPs), marks a pivotal shift in enhancing air traffic management efficiency and safety.

The Controller Working Position (CWP) stands as a critical element, serving as the operational hub for air traffic controllers. Today's CWPs vary significantly in their setup and functionality, depending on their application – be it for enroute or tower contexts. In enroute settings, the focus is on monitoring and managing aircraft across larger sectors of airspace, often using advanced radar and communication systems. In contrast, tower CWPs are tailored for airport environments, handling takeoffs, landings, and ground movements with a more immediate and localized focus.

The integration of a digital assistant into these contexts could revolutionize air traffic management. In enroute CWPs, the digital assistant could manage routine monitoring tasks, analyze traffic patterns for potential conflicts, and suggest optimal routing strategies. For tower CWPs, the assistant might focus on runway allocation, manage ground traffic efficiently, and aid in immediate conflict resolution. In remote towers, a digital assistant could provide enhanced visual and sensory data, compensating for the physical distance from the airfield and aiding in remote monitoring and management tasks.

To effectively integrate this digital assistant into the CWP, several options could be considered. A contextual window within the existing operational interface could provide seamless access to the assistant's functionalities, ensuring that controllers have uninterrupted access to critical information. Alternatively, a dedicated screen specifically for the assistant's outputs could offer a distinct and focused area for its insights and suggestions.

The modalities of interaction with the digital assistant are crucial for effective integration. Voice commands could offer a hands-free way to interact with the system, while text-based inputs could provide precision and clarity. Video feeds, particularly in remote tower setups, could offer real-time visual data essential for decision-making.

For notifications and alerts, a combination of visual, auditory, and haptic signals could be employed to suit different scenarios and controller preferences. Visual alerts might include color-coded warnings or flashing icons on the screen. Auditory alerts could range from subtle beeps to synthesized voice messages, ensuring that vital information is conveyed promptly. Haptic feedback, though less common, could provide an additional layer of alert through vibration or other tactile signals, particularly useful in high-noise environments or when visual and auditory channels are heavily engaged.

In conclusion, standardizing the integration of digital assistants across various CWPs in civil aviation, while considering the unique demands of each context, is crucial. Such integration not only enhances operational efficiency but also ensures a high level of safety, adaptability, and responsiveness in air traffic management.

3.5 Being monitored continuously by systems

In the envisioned future of air traffic control operations, the continuous monitoring of Air Traffic Controllers (ATCOs) by advanced systems is poised to revolutionize the landscape of safety, efficiency, and collaboration. Drawing from pioneering projects such as MAHALO, STRESS, MINIMA, and ARTIMATION [14, 15, 16, 17], there's a strategic shift towards leveraging Artificial Intelligence (AI) for **real-time assessment of ATCOs' mental states and activities**. Expert feedback emphasizing **mutual transparency and explainability** echoes the sentiment that systems should monitor not just mental states but also actions, such as fixation locus, to infer intentions and support needs. These insights align with the vibrant discussions held during workshops with ATCOs, where the emphasis was on dynamic responsibility allocation, adaptive task distribution, and resilience planning.

The integration of AI-driven continuous monitoring into the ATCO landscape promises multifaceted benefits. Firstly, it aims to **optimize human-AI collaboration** by facilitating a **mutual understanding** between systems and ATCOs, enhancing shared situation awareness and fostering effective collaboration. Such systems not only assess mental states but also interpret actions, allowing for timely intervention or support as per the situational demands. Furthermore, this approach embodies adaptability, **dynamically allocating responsibilities** between human operators and AI systems based on workload, environmental factors, and real-time demands. The ability to allocate tasks and responsibilities dynamically, as emphasized during discussions, ensures efficient resource utilization and response optimization.

However, amidst these advantages, there exist critical considerations and potential challenges. Foremost is the necessity to address **liability** and responsibility allocation in dynamically adaptive systems. Clarifying when and where the human intervention is required and associating liability with it is paramount for legal coverage, especially in automated functions like conflict detection. Additionally, the recognition of an "Emergency Mode" highlights the need to **anticipate and respond differently in crisis situations**, necessitating robust contingency planning. Another crucial aspect is the **resilience to failures**, as discussed during workshops, ensuring that the system can recover or operate safely in case of malfunctions or unexpected scenarios.

To materialize these futuristic concepts, advancements in AI transparency and explainability are imperative. Enhanced interfaces harmonizing human-machine interactions, coupled with comprehensive playbooks dictating task allocation in diverse situations, will be fundamental. Thus, the continuous monitoring of ATCOs' activity and mental states by advanced systems not only augments safety and efficiency but also demands meticulous attention to legal, ethical, and operational intricacies for successful integration into future air traffic control paradigms.

3.6 Differences between different ATCOs roles

The aviation sector is foreseen to live a transformative trajectory in the coming decades, driven by the integration of new technologies, particularly artificial intelligence (AI). These advancements are envisioned as pivotal tools that will support aviation operators in meeting the anticipated increase in traffic complexity, attributed to heightened demand and increased heterogeneity in air traffic.

As the industry moves into the future, the role of the Air Traffic Controller (ATCO) is poised for substantial evolution. The advent of AI is expected to gradually assimilate human tasks within the next 30 years, leading to important shifts in the workforce. Certain roles are projected to undergo metamorphosis, with the Tower ATCO transitioning into the role of a Tower Ops Manager. Simultaneously, other roles, such as the Pilot Monitoring, might become less important, making way for Single Pilot Operations (SPO). In this transformative phase, novel positions like the Air Traffic Manager, Flight Ops Ground Monitor, and Airport AI Operations Manager are poised to emerge.

By the year 2050, the human role in aviation operations is anticipated to pivot towards supervising system performance and intervening in cases of malfunctions, unexpected events, and emergencies. This shift, however, will be selective, predominantly impacting roles in the Air Traffic Management (ATM) where strategic planning remains a cornerstone.

Delving specifically into the realm of ATCOs, **En-route and Approach** controllers are projected to witness a convergence of tasks and responsibilities, culminating in the emergence of a novel position — the Air Traffic Manager. This transition is anticipated to materialise around 2035, concomitant with the integration of en-route and approach airspaces. During the ensuing period of 2035-2040, the Air Traffic Manager is slated to oversee nominal operations, managing both ATM and UTM traffic, with AI assuming a pivotal role in tactical and strategic de-confliction.

Concurrently, the **Tower** ATCO role is poised for a substantive transformation. By 2030-2035, AI is expected to augment Tower ATCOs in executing routine tasks, including communication instructions to pilots, as well as safety-critical responsibilities such as maintaining requisite aircraft separation during landing and take-off and improvements in LVP procedures. In the subsequent timeframe of 2040-2050, similarly to their en-route counterparts, Tower ATCOs are anticipated to transition into the role of Tower Ops Manager. In this capacity, they will take on more supervisory and managerial responsibilities, organizing operations at a higher level, participating in strategic planning, and getting involved, with AI support, in situations that are not normal and emergencies.

As highlighted by the HAIKU project, a realistic roadmap to 2050 would see several steps in which the role of the operators would shift towards monitoring and oversight. Steps development is supported by increasingly effective and reliable AI assistants. One possible outcome of this could be, as highlighted by experts during project's workshops, the merging of en-route executive and planner roles, with AI taking care of tasks related to the planner. Systems like CODA support this shift in roles, addressing the steps in which both ATCO and AI are sharing tasks and support each other.

Users expected benefits and limitations

Users' expectations regarding the future tasks of different ATCO roles, collected in a dedicated workshop are provided below. The main expected benefits are:

- Different ATCO roles agreed that AI could bring benefit by taking care of repetitive tasks, potentially increasing the ATCOs focus on tasks with more added value.

- All ATCO roles expect a positive impact on efficiency
- For en-route ATCOs, main expected benefits are the increase in capacity and the reduction in fuel burn. For en-route ATCOs the more positive impact is expected in a low traffic and predictable ACC environment. The improved support provided by the CODA system is expected to facilitate merging the role of Executive and Planner ATCOs
- Different ATCOs agreed that one of the main benefits generated by the system would be safety, reducing the possibility of human error.

Some limitations have also been identified:

- Future ATCO's competencies and qualities needed for working with such adaptable systems will change, impacting training and selection processes
- Trust and acceptability issues could limit or slow the adoption of the CODA system.
- Highly automated systems could lead to the ATCO's deskilling.
- In a busy and intricate, highly dynamic ACC environment, lower benefits are expected.
- One possible issue is related to the correct understanding of the proposal suggested by the AI
- Increased disruption issue in case of a failure in the digital assistant (e.g. Closure of airspace for a significant amount of time)
- The introduction of such a system would need the generation of ore radical emergency modes than nowadays
- Lot of work would be needed in order to ensure resilience and redundancy of the system.
- Need to investigate and assess the possible new liability responsibilities.

3.7 ATCO-supporting tools

One of the roles that will most benefit from the use of increasing levels of automation supported by AI is the Air Traffic Controllers. Current limitation in automation support is due to the fact that there is limited knowledge on the information that may impact a flight, and the traffic surveillance, conflict detection and conflict resolution must be done by the controller. However, some minimum support from automation tools is being introduced such as conformance monitoring or what-if capabilities for a trajectory change. This limited support implies that extra capacity is not exploited, and human effort needed to manage the traffic is still significant [9]

The SESAR master plan [11] foresees gradual introduction of automation in the controller operation room and moving from operator assistance to full automation. Intermediate levels targeting 2030-2035 would be:

- Level 2 Partial assistance, with anticipation and execution of some aspects of the control task by assistance system in nominal conditions with the human operator performing all remaining aspects of the control tasks, ready to take back control immediately if needed.

- Level 3 Conditional automation in which the Automation supported by AI anticipates and executes most aspects of control task in nominal conditions, and the human intervenes upon system request.

In these automation environments no dramatic change is foreseen. Main characteristics are that new tools will be more oriented to the airspace specific aspects and traffic complexity allowing the controller to have less need of sector-specific training. The new tools will be able to provide more precise information thanks to the sharing of information among the different ATS, see 3.2 Sharing of data with a wider group of stakeholders, and the identification of patterns obtained using machine learning/deep learning.

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Main characteristics of the En-route environment where ATCOs work are:

- **Free route airspace**: cross-border and cross-FIR free route airspace is implemented together with advanced Use of Airspace. Minimal constrains are put in place to ensure the orderly integration of flows when and where needed.

- **Dynamic Airspace Configuration**: sectors shape adapts to traffic considering free route airspace, complexity and uncertainty in the traffic and human (ATCO) necessity to have internal knowledge of sector boundaries.

- **Trajectory based Operations**: optimised, accurate and constantly updated 4D flight plans and 4D trajectories are shared among all the stakeholders.

- **Sectorless/ flight centric operations**: changes the responsibility of controller from being responsible of a piece of airspace to controlling a number of flights along their trajectories.

Next tools will support the controllers in this environment ([10] and [12])

- **Enhanced monitoring conformance service:** (MONA) for both tactical and planning controllers. Enhanced MONA includes a new alert to take into account lateral deviation and the rate change monitoring in climbing and descending phase to minimise false alerts. It will consider not only the flight plan and its updates, but also the **intent monitoring**, ensuring that airborne and ground trajectories are aligned.

- **Improved trajectory predictions:** The use and process of more accurate information (complete download to ground system of aircraft data, as intended trajectory, status of flight, new Meteorogolical data, capabilities, …) supports the improvement in trajectory predictions that feed other controller tools.

- **Detection of aircraft penetration:** if segregated airspace is in place, providing trajectory-based resolution.

- **Automated support for Traffic complexity detection and resolution**: Automated tools support the ATC team in identifying, assessing and resolving local complexity situations. It relies on a real time integrated process for managing the complexity of the traffic with capability to reduce traffic peaks through early implementation of measures for workload balancing Traffic Complexity Assessment and Individual Traffic Complexity based solutions.

- **Enhanced tactical conflict detection & resolution (CD&R) services**: rely on the use of improved 4D trajectory prediction allowing to increase the conflict detection horizon, enabling a better anticipation and the management of larger sectors, strongly reducing the number of false conflicts alerts. The CD&R services also rely on **the ability to provide various resolution options** (e.g. trajectory modification, speed adjustments via CTO allocation) taking into account flights under time constraint (e.g. flight time status display).

- **RBT revision supported by datalink and automation**: RBT revisions processes assess the impact of a trajectory revision, by comparing various options, selecting the most efficient one. It takes advantage of the increased amount and usefulness of air-ground information and automation support to controllers and pilots: e.g. automatic uplink of clearance with or without controller validation.

- **New HMI interaction modes**: to minimize the load and mental strain of controllers, include adaptative automation, attention control, augmented reality, etc.

- **Improved vertical clearances**: The ATC system would generate proposals for conflict-free clearances that take anticipated aircraft performance into account, which can be uplinked to the flight crew by ATCO.

- **System supported coordination tools.** Full ATC-ATC interoperability mechanism is in place and a single representation of the flight is simultaneously available at all sectors. Reducing the coordination needs (silent coordination for situations that do not require a trajectory revision) and allowing screen to screen inter sectors or inter ATSUs coordination (Coordination and Transfer and Airspace Crossing Dialogues, where needed, with What-If trajectories proposals for resolution of cross border separation and other concerns).

- **Workload monitoring** is managed between the planification roles (planning controllers, Extended air traffic ocontrollers and local traffic managers) with decisions taken through - (airspace reorganisations, punctual actions on traffic or more global actions, e.g. on a flow of traffic in which the flight is included). As complexity in very busy airspace may be high, automated support to the Planner is provided to identify, assess and resolve local complexity in a dynamic airspace management environment.

3.8 Adaptive interfaces

In the rapidly evolving domain of air traffic management (ATM), the integration of Adaptive Interfaces (ADP) stands as a pivotal innovation, promising to enhance the efficiency and safety of air traffic control. These interfaces are designed to align with the dynamic nature of airspace and the changing operational demands of air traffic controllers. At the core of this technological leap are three critical indicators: the complexity of air traffic, the physiological state, and the mental state of the controllers. These indicators are integral in ensuring that the support tools provided are in sync with the controllers' current operational and cognitive needs.

To actualize this alignment, the system must exhibit a high degree of adaptability. The effectiveness of such adaptation hinges on the controller's understanding of the rationale behind these changes. It is essential that controllers can utilize these adaptive tools with a sense of confidence and comprehension. Building and reinforcing this trust involves providing clear explanations for the system's adaptations. This is where interactive data visualization tools come into play, serving as a conduit for enhancing understanding and confidence in the system.

To further amplify the effectiveness of these explanations, advanced data representation techniques, including virtual and augmented reality methods, are employed. These sophisticated techniques offer an immersive and intuitive understanding of the system's adaptations. However, it's crucial to note that these explanations are not obligatory but available upon the controller's request. In standard operational contexts, the system adapts autonomously, without explanations. Explanations and data representations are provided only when necessary, ensuring that the system's adaptability does not overwhelm or distract the controller.

Adaptive interfaces in ATM are categorized into several key functionalities, each designed to dynamically respond to varying air traffic conditions and controller states:

Supervision/Monitoring Interfaces: Future interfaces might include holographic radar displays, offering a 3D visualization of air traffic. This could allow controllers to perceive and assess complex traffic scenarios more intuitively, with the system adjusting the level of detail based on traffic volume and controller workload.

Alarm Systems: Advanced auditory interfaces, such as 3D spatial audio alarms, could be used. These would provide directional cues to the source of a potential conflict, making it easier for controllers to pinpoint issues in a busy airspace, with alarm intensity adapting to the urgency of the situation.

Clearance Procedures: AI-driven voice recognition systems could automate routine clearances, allowing controllers to focus on more complex tasks. These systems would analyze traffic density and controller workload to decide when to offer automated assistance.

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Grouping/Degrouping of Sectors: AI algorithms could suggest optimal sector groupings in real-time, based on traffic patterns and controller capacity. For instance, in times of low traffic, the system might recommend degrouping sectors for more focused management, using predictive analytics to anticipate traffic surges.

Flight allocation: in a sectorless environment such as a flight-centric airspace, the AI algorithm could suggest optimal allocation of flights in real-time taking into account traffic patterns and trajectory and controller capacity.

Incorporating these advanced technologies into adaptive interfaces represents a stride towards a more efficient, responsive, and safe ATM system, paving the way for a future where ATM is both resilient and adaptable.

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4 Functional architecture view

4.1 SESAR solution overview

As is common to all types of automation, as long as the human operator is in control, s/he needs to be able to understand everything that goes on under the operator's responsibility. Hence, if an AI application supports the operator, it must keep the operator in the loop regarding its reasoning and decisions. This is called **Human-AI Teaming.** However, the more tasks AI executes, the more there will be to explain to the human operator. Therefore, AI needs to have a good understanding of what the human is doing when the AI wants to demonstrate its reasoning, at what level explanation is required and when it can interfere and when not. In other words, AI should become more Human Centric. In the ATC domain, the idea of AI as an advisor of the ATCO to support them in training or during real operations is a research topic that different partners in SESAR-funded projects are working on [1].

The Digital European Sky vision recognises that the future ATM environment will be **increasingly complex**, with new airspace vehicles flying at different speeds and altitudes, compared with conventional aircraft. Moreover, there will be increasing pressure to reduce the costs of the ATM infrastructure while improving performance [1].

It is expected that AI will provide the additional capacity to meet the challenges of increasing air traffic complexity due to sustained growth and new airspace users and support more efficient and environmentally friendly operations while maintaining and increasing current safety levels. AI is expected to carry out some specific tasks and to support operators in other ones, from the tactical management of traffic done by Air Traffic Controllers (ATCOs) to the organisation of flows at network level. The increasing use of AI in the ATM field entails **the risk of generating an inadequate integration between man and machine, making AI developments losing efficiency, if not even causing problems or accidents.**

CODA aims at contributing to overcome such a problem by focusing on how to better integrate the new generation of automated tools, based on AI, with human operators, thus avoiding any issues related to out of the loop syndrome, lack of understanding of system behaviour and lack of control. Specifically, the project wants to provide a concrete example of **an adaptable system, in which AI not only is aware of what the human counterpart is doing but could also predict future problems and act accordingly**.

The introduction of the digital assistance proposed by the project will support operators in carrying out their tasks, reducing the workload levels and enhancing their performances:

- exploiting automation up to its higher levels to perform non-critical tasks,
- adapting the human-machine interface with different explainability levels,
- foreseeing possible future problems and preventing them.

It must be highlighted that the goal is not automation per se but optimising the overall performance of the sociotechnical ATM system and always maximising human performance and engagement.

To make that more concrete:

CODA enhances adaptability in highly automated systems by managing the interaction of AI tools and other support systems with Air Traffic Controllers based on their current and anticipated mental states. The system includes:

- A tasks prediction module,

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- A mental states assessment module,
- A mental states prediction module,
- An adaptive automation strategy module.

As already presented in D2.2 OSED, the CODA system enables a better integration of any AI-based tools supporting the work of en-route Air Traffic Controllers (but the solution could easily be applied to other controllers' roles), improving teaming, wellbeing, safety and performance, and keeping the mental state of the controller within safe boundaries.

In particular, the expected benefits of the solution for the main targeted stakeholder (ANSPs) will be to:

- Improve operations predictability,
- Improve/Maintain level of safety in ATM,
- Increase airspace capacity,
- Increase operational efficiency,
- Reduce costs due to inefficiency and unexpected complex/unsafe situations.

4.1.1 Supporting reasons for this SESAR solution

The CODA system enables a better integration of any AI-based tools supporting the work of en-route Air Traffic Controllers. In particular, the solution adopts a user-centred approach by involving the relevant stakeholders (ANSPs, airport operators, airspace users and the Network Manager) in defining, developing and deploying a concept that meet Europe's policy objectives on aviation and air transport.

Regarding the wider expected impact of the project, CODA results are expected to make a difference beyond the immediate scope and duration of the project. In the long term, the CODA project will have an impact in many of the research and innovation needs addressed in the SRIA to achieve the Digital European Sky programme. In detail, the CODA project will have an impact on:

- **Connected and Automated ATM.** The Digital Assistance Tool will boost the level of automation in the ATM. This will contribute to achieving the European ATM Master Plan vision to reach at least level 2 (task execution support) for all ATC tasks and up to level 4 (high automation) for some of the tasks.

- **Capacity-on-demand and dynamic airspace.** The CODA system will allow a dynamic reconfiguration of resources (HUMAN-AI TEAMING) and new capacity-on-demand (ADAPTIVE AUTOMATION FOR TASK ALLOCATION AND EXECUTION) services to maintain safe, resilient, smooth and efficient air transport operations while allowing for the optimisation of trajectories, even at busy periods.

- **Artificial intelligence (AI) for aviation.** The predictivity and prescriptibility of the system will optimise the ability to identify potentially problematic solutions and to correct them before the event occurs.

The CODA Project demonstrates a significant contribution to the realisation of the Digital European Sky vision (SESAR Phase D) in relation to achieving:

- fully scalable services supported by a digital eco-system, providing an enabler for adaptable systems able to effectively respond and anticipate disruptions and problematic situations,
- high and full automation (level 4/5), providing a concrete example of a system adapting the level of automation to the contextual condition and the states of operators, ensuring the best possible level of automation in the different conditions.

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4.1.2 ATM capabilities addressed by the SESAR solution

The CODA system, as a cutting-edge SESAR solution, epitomizes the next generation of Air Traffic Management (ATM) through its strategic application of Artificial Intelligence (AI). This system brings to the table a myriad of enhanced ATM capabilities: from providing **real-time decision support** for dynamic traffic scenarios, **predictive analysis** to anticipate traffic patterns and potential conflicts, to **enhanced safety measures** through AI-driven safety protocols. CODA's brilliance lies in its ability to streamline **operational efficiency**, ensuring optimal airspace utilization and reduced delays. At its core, CODA champions **Human-AI collaboration**, meticulously maintaining the balance where Air Traffic Controllers (ATCOs) are constantly kept in the loop, informed, and in control. Additionally, it demonstrates remarkable **scalability and adaptability**, ready to adjust to varying levels of air traffic and diverse operational environments. These capabilities collectively facilitate operational predictability, improved safety, and efficiency in ATM. CODA's holistic approach not only adapts to and mitigates airspace complexities but also customizes AI assistance, focusing on cognitive support and decision-making processes for ATCOs. As a result, there's an increase in airspace capacity, a rise in safety levels, and a significant reduction in operational costs, thereby advancing towards the realization of a Digital European Sky. CODA is a testament to the seamless integration of AI in ATM systems, maximizing human performance and engagement, while adeptly navigating the ever-evolving terrain of civil aviation.

SESAR solution capabilities	Comments on potential updates required at capability level
Predictive Analysis	Develop more advanced algorithms to handle unpredictable flight patterns, incorporate machine learning to refine predictions over time, and integrate broader data sets (like global traffic trends) for more accurate forecasting.
Enhanced Safety Measures	Introduce more sophisticated anomaly detection algorithms, improve response protocols for identified risks, and enhance AI's ability to learn from past incidents for better future risk management.
Operational Efficiency	Automate more routine tasks to free up ATCOs for complex decision-making, refine AI algorithms for better traffic flow management, and enhance system interoperability with other international ATM systems.
Human-AI Collaboration	Improve AI user interface for easier interpretation and interaction, incorporate adaptive learning to better understand ATCO preferences and responses, and enhance training programs to keep pace with AI advancements.
Scalability and Adaptability	Develop more flexible AI models to adapt to rapidly changing airspace conditions, enhance system scalability to handle unexpected surges in air traffic, and improve adaptability to new types of airspace users, like drones or urban air mobility vehicles.

Table 3: CODA capabilities

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The Requirements Breakdown Structure (RBS) for the CODA system within the SESAR solution is a meticulously designed framework that categorizes and details the diverse and complex requirements essential for the effective implementation of this advanced Air Traffic Management system. At the highest level, the RBS is segmented into four principal categories: Technical, Operational, Safety and Compliance, and Human Factors. The **Technical Requirements** focus on the development and integration of sophisticated AI algorithms, robust data processing capabilities, and seamless system integration, ensuring that the technical backbone of CODA is both powerful and reliable. In the **Operational Requirements**, the emphasis is placed on achieving real-time responsiveness, maintaining high accuracy and efficiency, and developing a user-friendly interface that allows Air Traffic Controllers to interact with the system intuitively. The **Safety and Compliance Requirements** are paramount, encompassing adherence to stringent safety standards, implementing effective risk mitigation strategies, and ensuring that the system complies with international aviation regulations. Lastly, the **Human Factors Requirements** address the crucial aspects of user training, ergonomic design, and cognitive load management, ensuring that the system is not only effective but also aligns with the natural workflows and decision-making processes of the ATCOs. Each of these major groupings branches further into specific sub-requirements, creating a comprehensive map that guides the development, implementation, and continuous improvement of the CODA system, ultimately enhancing the efficiency, safety, and adaptability of air traffic management in the ever-evolving landscape of civil aviation.

4.1.3 Stakeholders impacted by the SESAR solution

Stakeholder		Why it matters to the stakeholder
Scientific community (Universities, research institutions, EU projects, educational institutions)	To disseminate the project objectives, intermediate and results of the project, potentially finding synergies with other projects/approaches focused on the implementation of higher levels of automation and AI within ATM through scientific dissemination, workshops, etc.	To raise mutual awareness of approaches results potentially resulting in further collaborations To make students and academia aware of advanced AI solutions in ATM, helping to entice them to this knowledge area.
Institutional bodies (EU and EC, European Joint Undertakings, EASA, Policy makers, Regulatory and safety agencies, Standard making bodies, National bodies, Certification bodies).	To provide an actionable roadmap for the progressive and controlled deployment of AI solutions through direct links though the Advisory Board and dissemination events	To help facilitate the progressive and safe introduction of AI solutions in ATM in a controlled way, by implementing actual examples of potential uses to help confidence to be built on the users and regulators and helping define future safety/security/privacy constraints for its implementation.
Industry (ATM automation systems providers).	To make industry aware of the potential and results of our project for final implementation using direct links with industries and dissemination events	To provide a clear path for the higher TRLs implementation of the solution, and potentially opening the way to more AI based solutions implementation.
Users (ATCOs, ANSPs, NM).	To promote solution benefits and potential applications to the ANSPs	To start the journey to finally deploy in future a CODA based solution, with the help of the

	and Network Management stakeholders at large using NM fora and communication channels, and direct relations with some ANSPs and ATCO organizations (e.g., ENAIRE, IFATCA).	industry to reach higher levels of TRL, in actual operations To inform Decision Makers and incentivise operational stakeholders to adopt CODA solution
General public, media.	To raise awareness on CODA objectives and results in the general public	To make clear the value of the project and the benefits for citizens, especially in terms of safety and economy impacts.

Table 4: CODA solution stakeholders' expectations and involvement

A detailed description of the expected impact on the main ATM stakeholders (ANSPs and Airspace Users) is provided in D2.2 OSED.

4.2 SESAR solution functional view

4.2.1 Interaction(s) identification

This sub-section delineates the interactions between various capability configurations and technical systems within the CODA framework, a part of the SESAR solution. These interactions encompass both existing synergies and potential new services emerging from novel interfaces.

<u>Functionality and Architecture</u>

The CODA system is architecturally designed to facilitate seamless interaction between multiple capability configurations and technical systems, each serving a distinct yet integrated function within the Air Traffic Management (ATM) landscape.

- **Real-time Decision Support & Predictive Analysis System**: This technical system functions as the cognitive core of CODA, providing AI-driven support and predictive insights to Air Traffic Controllers (ATCOs). It interacts with real-time air traffic data systems, processing vast amounts of information to aid in decision-making and traffic prediction.
- **Safety Protocol Interface:** Integrated with the decision support system, this interface enhances the overall safety measures by continuously monitoring and analysing traffic data for potential risks, thereby triggering appropriate safety protocols when needed.
- **Operational Efficiency Optimizer:** This system interacts with both the decision support and safety protocol interfaces, streamlining operational processes. It ensures optimal airspace utilization, minimizes delays, and enhances communication and coordination among various stakeholders in ATM.
- **Human-AI Teaming Interface**: A critical component that ensures effective collaboration between AI systems and ATCOs. It provides an intuitive user interface, allowing ATCOs to understand and interact with AI recommendations easily.
- **Scalability and Adaptability Engine**: This configuration is designed to dynamically adjust to varying levels of air traffic and different operational environments. It interacts with all other systems, ensuring that the CODA solution remains effective and efficient under diverse conditions.

<u>Operations Performed</u>

Each of these configurations and systems performs specific operations:

- **Real-time Decision Support & Predictive Analysis System**: Processes real-time data for immediate decision support and long-term traffic predictions.
- **Safety Protocol Interface**: Monitors for anomalies or risks and activates safety measures as required.
- **Operational Efficiency Optimizer**: Aligns flight paths, manages traffic flows, and coordinates operations for enhanced efficiency.
- **Human-AI Teaming Interface**: Facilitates the flow of information and insights between AI systems and ATCOs, ensuring clarity and usability.
- **Scalability and Adaptability Engine**: Continuously analyses system performance and traffic patterns, adapting operational strategies accordingly.

<u>Summary of Functionality Related to Interfaces</u>

Each capability configuration and technical system is intricately linked, with a special emphasis on their functionality relating to the interfaces:

- The **Real-time Decision Support & Predictive Analysis System** interfaces with data sources and other AI components, forming the backbone of AI-driven decision-making in ATM.
- The **Safety Protocol Interface** ensures a direct link between real-time risk assessment and safety response mechanisms, crucial for maintaining high safety standards.
- Through the **Operational Efficiency Optimizer**, there is a direct impact on the flow and management of air traffic, influenced by the data and insights provided by other systems.
- The **Human-AI Teaming Interface** is pivotal in maintaining a transparent and effective interaction between ATCOs and the AI systems, influencing how information is presented and actions are suggested.
- Finally, the **Scalability and Adaptability Engine** is the connective tissue that allows the CODA system to remain flexible and responsive, adapting to changes in air traffic patterns and operational demands.

This interplay of systems and interfaces within CODA exemplifies a sophisticated, integrated approach to enhancing ATM, aligning with the broader objectives of the SESAR initiative.

4.2.2 Functional decomposition

This section offers a detailed functional decomposition of the capability configurations and technical systems required for the CODA system within the SESAR solution framework. This breakdown aligns with the latest applicable version of the SESAR architecture, noting any deviations for further consideration at higher Technology Readiness Levels (TRLs).

<u>Capability Configurations Decomposition</u>

- **Real-time Decision Support & Predictive Analysis System**
    - *Technical Systems*: Advanced AI algorithms, real-time data processing units, predictive modelling tools.
    - *Roles*: Data analysts, AI specialists, system integrators.
- **Safety Protocol Interface**

- *Technical Systems*: Risk assessment algorithms, safety protocol management, anomaly detection systems.
- *Roles*: Safety engineers, risk management specialists.

- **Operational Efficiency Optimizer**
  - *Technical Systems*: Traffic flow management tools, communication coordination systems, operational efficiency analytics.
  - *Roles*: Operations managers, efficiency analysts.
- **Human-AI Teaming Interface**
  - *Technical Systems*: User interface design tools, AI-human interaction modules, training and simulation programs.
  - *Roles*: Human factors experts, interface designers, training specialists.
- **Scalability and Adaptability Engine**
  - *Technical Systems*: Adaptive AI models, scalability testing tools, environmental analysis software.
  - *Roles*: Scalability experts, environmental analysts, AI experts.

<u>**Functional Breakdown**</u>

Each capability configuration is further broken down into its constituent functional elements:

- **Real-time Decision Support & Predictive Analysis System**: AI Algorithm Development, Data Processing and Analysis, Predictive Modeling and Scenario Simulation.
- **Safety Protocol Interface**: Risk Assessment Algorithm Design, Safety Protocol Development and Management, Anomaly Detection and Response Mechanisms
- **Operational Efficiency Optimizer**: Air Traffic Flow Optimization, Communication and Coordination Enhancement, Efficiency Analysis and Reporting
- **Human-AI Teaming Interface**: Interface Design and Usability Testing, AI-Human Interaction Protocols, ATCO Training Programs and Simulations
- **Scalability and Adaptability Engine**: Adaptive AI Model Development, Scalability Analysis and Testing, Environmental Impact Assessment

4.3 High level impact of the SESAR solution on the baseline SESAR architecture

No expected impact.

5 Functional requirements

The following paragraphs detail the CODA high level functional requirements. Each paragraph is related to a specific topic (potentially) impacting ATCO future roles. The following eight topics are described in terms of requirements for each identified future role:

- Artificial intelligence (AI) wide usage,
- Sharing of data with a wider group of stakeholders,
- Planning and monitoring rather than active controlling,
- More standardisation between sectors, towers, CWPs,
- Being monitored continuously by systems,
- Differences between different ATCOs roles,
- ATCO-supporting tools,
- Adaptive interfaces.

The requirement statement translates or expresses a need and its associated constraints and conditions. Requirements express the WHAT, not the HOW. The focus is on stating the need rather than imposing a solution; this is why it is important not to constrain more than necessary at the considered level. Requirements should avoid imposing specific implementation choices unless they are strictly necessary (e.g., for ensuring interoperability). In this case the HOW shall be justified.

Within this phase of the project, that status of each identified requirement is either *<in progress>* or *<not applicable for CODA solution>*. A requirement is *<in progress>* when it is considered as an actual requirement but not yet validated by means of validation exercises. A requirement is *<not applicable for CODA solution>* when it is *not* considered for the CODA solution but kept for future reference.

5.1 Artificial Intelligence (AI)

Identifier	**REQ-SOL0447-FRD-AI01.0001**
Title	*Explainability of the solution*
Requirement	The AI shall provide details on the solution proposed under demand.
Status	<in progress>
Rationale	*To build trust and acceptance on the system, the operator should be able to understand the reason for the proposed solution. The details to be provided will depend on the solution proposed. Being CODA TRL2 project, solutions easy to explain should be preferred for validation.*
Category	<Functional>, <Design>, <HMI>

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Identifier	**REQ-SOL0447-FRD-AI01.0002**
Title	*Personalisation of the solution*
Requirement	The AI shall personalise the solution considering the human operator
Status	<in progress>
Rationale	Acceptance of the AI solutions can be achieved through personalization of the AI to the controller. This is one of the objectives of CODA as the current and future mental states are considered by the system.
Category	<Functional>, <Design>, <Interoperability>, <Interface>

Identifier	**REQ-SOL0447-FRD-AI01.0003**
Title	*Stakeholder and field experts involvement.*
Requirement	The AI shall propose solutions that have been validated by stakeholders or experts in the field
Status	<in progress>
Rationale	*To ensure the AI solutions are usable by the end user. The solution booklet that will contain the possible solutions of the AI-controller teaming will be developed by CODA members which are experts in the fields.*
Category	<Design>

Identifier	**REQ-SOL0447-FRD-AI01.0004**
Title	*Safety assessment.*
Requirement	The system safety assessment shall include an AI failure mode
Status	<not applicable for CODA solution>
Rationale	*The impact and probability of AI malfunction is needed to be able to put the system into operation and develop contingency strategies. Being CODA TRL2 project, the safety assessment is out of scope.*

Category	<Design>

Identifier	**REQ-SOL0447-FRD-AI01.0005**
Title	*Learning assurance*
Requirement	The AI shall use reliable and validated data sets to be trained
Status	<in progress>
Rationale	*Data sets can introduce biases in the AI during the learning phase. Some of the data sets that will be used in CODA are reliable and validated (e.g. the ones provided by an ANSP) but others should be analysed due to the low amount of data available. Although this is understandable due to the exploratory nature of the project, possibles biases should be detected and documented.*
Category	<Data>, <Design>, <Reliability>

5.2 Sharing of data with a wider group of stakeholders

The Air Traffic Control (ATC) system shall be designed to anticipate and meet the evolving demands of the future aviation landscape by enabling the Sharing of Data (SOD) with an expanding and diverse group of stakeholders.

Identifier	**REQ-SOL0447-FRD-SOD02.0001**
Title	**Enhanced Real-time Data Sharing**
Requirement	The system shall enhance real-time sharing of dynamic data, including real time states of operators, expected states, predictive analytics, machine learning algorithms decisions in terms of system adaptation
Status	<in progress>
Rationale	By incorporating these elements, the system aims to support timely insights, streamline coordination, and improve adaptability to changing circumstances. This approach also contributes to optimized resource allocation, continuous improvement through learning from historical data, and enhanced safety and situational awareness. Ultimately, the integration of advanced technologies serves to make the ATC system more agile, responsive, and effective in managing air traffic in a dynamic aviation environment.

Category	<Functional>, <Safety>, <Security>, <Adaptability>, <Maintainability>, <Reliability>, <Performance>, <Data>, <Design>, <Interoperability>, <Interface>, <HMI>,

Identifier	**REQ-SOL0447-FRD-SOD02.0002**
Title	**Adaptive Interoperability**
Requirement	The system shall exhibit adaptive interoperability, allowing for seamless data exchange with emerging technologies, novel communication protocols, and a growing array of stakeholders.
Status	<in progress>
Rationale	As aviation technologies and stakeholder ecosystems evolve, the system needs to seamlessly integrate with emerging technologies, novel communication protocols, and an expanding array of stakeholders. This ensures that the ATC system remains versatile, can accommodate new advancements without disruption, and sustains effective communication and data exchange in the dynamic landscape of aviation. Adaptive interoperability is essential for maintaining the system's relevance, compatibility, and efficiency in the face of ongoing technological advancements and an ever-growing network of stakeholders in the aviation industry.
Category	<Functional>, <Safety>, <Security>, <Adaptability>, <Maintainability>, <Reliability>, <Performance>, <Data>, <Design>, <Interoperability>, <Interface>, <HMI>,

Identifier	**REQ-SOL0447-FRD-SOD02.0003**
Title	**Cyber security challenges**
Requirement	ATC system shall aim to stay ahead of future cybersecurity challenges
Status	<not applicable for CODA solution>
Rationale	This approach anticipates and proactively addresses potential cyber threats, ensuring the integrity and confidentiality of sensitive data within the system. It fortifies the ATC infrastructure against emerging cyber risks, safeguarding critical information from unauthorized access, data breaches, and malicious activities.
Category	<Security>

Identifier	**REQ-SOL0447-FRD-SOD02.0004**
Title	**Compliance with privacy regulations**
Requirement	The privacy measures shall be aligned with the evolving privacy regulations
Status	<in progress>
Rationale	This ensures that the ATC system remains in compliance with emerging privacy standards, protecting the privacy rights of individuals and organizations involved in air traffic operations. By prioritizing data protection and confidentiality, the system establishes trust and accountability, meeting regulatory expectations and safeguarding against potential legal and ethical challenges related to privacy breaches.
Category	<Security>

Identifier	**REQ-SOL0447-FRD-SOD02.0005**
Title	**Data resilience and sustainability**
Requirement	The system shall be designed to ensure data resilience and sustainability, considering the potential increase in data volume and the importance of maintaining operational continuity during unforeseen events.
Status	<in progress>
Rationale	The rationale for focusing on data resilience and sustainability is rooted in the necessity to adapt to the increasing volume of data, maintain operational continuity during unforeseen events, ensure long-term viability, and mitigate risks to enhance the overall reliability of the Air Traffic Control system. This approach is vital for building a system that can withstand the challenges of a dynamic and evolving aviation landscape.
Category	<Data>

5.3 Planning and monitoring rather than active controlling

The integration of AI into ATM marks a paradigm shift in the role of ATCs, moving from direct control to planning and monitoring. While challenging, this transition holds immense potential for enhancing safety, efficiency, and overall ATM capabilities. Traditionally, ATCs have been responsible for direct control of aircraft movements, issuing clearances and ensuring safe separation. However, the increasing complexity of airspace and the growing volume of air traffic demand a more strategic approach. With AI, ATCs can transition from hands-on control to strategic planning and monitoring. AI will not replace ATCs: instead, it will serve as a powerful tool to augment their expertise. AI algorithms can analyse vast amounts of data, identify potential conflicts, and optimize traffic flows,

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providing ATCs with valuable insights and decision-support tools. ATCs will retain ultimate control, utilizing AI recommendations to make informed decisions. To ensure a smooth transition, the following functional requirements must be met.

Identifier	**REQ-SOL0447-FRD-PM03.0001**
Title	**AI-Assisted Decision Support**
Requirement	AI systems shall provide decision support to air traffic controllers in planning and monitoring roles.
Status	<in progress>
Rationale	It is essential for strategic planning that AI systems analyse data, predict traffic patterns, and offer optimized solutions, empowering controllers to make informed decisions.
Category	<Functional>, <Safety>, <Performance>, <Data>, <Design>, <Interoperability>, <Interface>, <HMI>

Identifier	**REQ-SOL0447-FRD-PM03.0002**
Title	**Dynamic Capacity Management**
Requirement	AI-powered optimization tools shall assist air traffic controllers in planning efficient and safe traffic flows, minimizing delays and reducing congestion.
Status	<in progress>
Rationale	It is critical for planning that air traffic controllers have the ability to optimize airspace and airport resources in response to changing demand, for example to dynamically adjust airspace and airport capacity plans based on real-time traffic variations and operational needs.
Category	<Functional>, <Adaptability>, <Reliability>, <Performance>, <Data>, <Design>, <Interoperability>

Identifier	**REQ-SOL0447-FRD-PM03.0003**
Title	**Predictive Analytics**
Requirement	Predictive analytics tools shall enable users (air-traffic controllers, supervisor) to anticipate traffic patterns, weather events, and potential disruptions.
Status	<in progress>
Rationale	Predictive analytics enable controllers to proactively plan and allocate resources, minimizing the impact of unforeseen events. Predictive analytics tools help controllers anticipate traffic patterns, weather events, and potential disruptions, contributing to proactive planning.
Category	<Functional>, <Safety>, <Performance>, <Data>, <Design>, <Interoperability>

Identifier	**REQ-SOL0447-FRD-PM03.0004**
Title	**Human-Machine Interface (HMI) Design**
Requirement	User-friendly and customisable HMIs shall clearly present real-time data, AI recommendations, and decision-support tools.

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Status	<in progress>
Rationale	User-friendly HMIs are crucial for monitoring as intuitive interfaces enhance situational awareness and streamline communication, allowing controllers to oversee AI-generated plans effectively. Visualizations should be clear, concise, and adaptable to individual preferences, minimizing distractions and cognitive overload.
Category	<Functional>, <Safety>, <Security>, <Adaptability>, <Performance>, <Design>, <Interface>, <HMI>

Identifier	**REQ-SOL0447-FRD-PM03.0005**
Title	**Training Simulators**
Requirement	Training simulators shall allow air traffic controllers to receive comprehensive training on the AI-powered system's functionalities, limitations, and human-AI collaboration protocols through interacting with AI systems in realistic scenarios.
Status	<not applicable for CODA solution>
Rationale	It is important for both planning and monitoring tasks that simulators help controllers practice interacting with AI systems, familiarize themselves with AI-driven processes and build confidence in their new roles. The training shall include hands-on experience, scenario-based exercises, and ongoing support to ensure that ATCs are comfortable using the system effectively.
Category	<Functional>, <Safety>, <Adaptability>, <Performance>, <Interface>, <HMI>

Identifier	**REQ-SOL0447-FRD-PM03.0006**
Title	**Collaborative Decision-Making Tools**
Requirement	Dedicated tools shall support collaborative decision-making between controllers, airlines, and other stakeholders.
Status	<not applicable for CODA solution>
Rationale	Effective communication and coordination are essential for optimizing air traffic management in collaboration with AI. It is critical for both planning and monitoring tasks that the tools support effective communication and collaboration between controllers and AI systems, facilitating decision-making
Category	<Functional>, <Safety>, <Reliability>, <Performance>, <Data>, <Design>, <Interoperability>, <Interface>, <HMI>

Identifier	**REQ-SOL0447-FRD-PM03.0007**
Title	**Ethical Decision Support**
Requirement	Ethical decision support features shall be embedded into AI systems, addressing considerations such as environmental impact and fairness in resource allocation
Status	<not applicable for CODA solution>

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Rationale	It is important for the planning process, that AI systems embed ethical decision support features to address considerations such as environmental impact and fairness in resource allocation
Category	<Functional>, <Performance>, <Design>, <Interface>, <HMI>

Identifier	**REQ-SOL0447-FRD-PM03.0008**
Title	**Real-time Monitoring Dashboards**
Requirement	Dashboards shall provide real-time information on AI-generated plans and overall air traffic conditions.
Status	<in progress>
Rationale	Controllers need up-to-date information to monitor the airspace and respond promptly to changing circumstances. Dashboards are crucial for monitoring as they provide real-time information on AI-generated plans and overall air traffic conditions, supporting controllers in their monitoring responsibilities
Category	<Functional>, <Safety>, <Adaptability>, <Performance>, <Data>, <Design>, <Interface>, <HMI>

Identifier	**REQ-SOL0447-FRD-PM03.0009**
Title	**Adaptive Displays**
Requirement	Displays shall allow controllers to customize the information presented based on their preferences and the current operational phase
Status	<in progress>
Rationale	Adaptive displays are important for monitoring, as they allow controllers to customize information presentation, enabling them to focus on the most relevant information during the planning and monitoring phases.
Category	<Functional>, <Safety>, <Adaptability>, <Design>, <Interface>, <HMI>,

Identifier	**REQ-SOL0447-FRD-PM03.0010**
Title	**Alerts and Notifications**
Requirement	Effective alerting and notification systems shall highlight critical information or deviations from AI-generated plans.
Status	<in progress>
Rationale	Timely alerts ensure controllers are promptly informed of important events that may require intervention. Effective alerting and notification systems are critical for monitoring tasks, as they highlight critical information or deviations from AI-generated plans, aiding controllers in their monitoring role.
Category	<Functional>, <Safety>, <Reliability>, <Performance>, <Design>, <Interface>, <HMI>

Identifier	**REQ-SOL0447-FRD-PM03.0011**

Title	**Feedback Mechanisms**
Requirement	Mechanisms for controllers shall be integrated to provide feedback on AI-generated plans and system performance.
Status	<not applicable for CODA solution>
Rationale	Feedback mechanisms are important for both planning and monitoring as they allow controllers to provide insights on AI-generated plans and system performance, contributing to continuous improvement in both phases. Continuous feedback loops support the refinement and improvement of AI systems based on real-world operational experiences
Category	<Functional>, <Safety>, <Adaptability>, <Reliability>, <Performance>, <Data>, <Design>

Identifier	**REQ-SOL0447-FRD-PM03.0012**
Title	**Cybersecurity Measures**
Requirement	Robust cybersecurity measures shall protect AI systems from potential threats and ensure the integrity of air traffic management
Status	<not applicable for CODA solution>
Rationale	Security is paramount, especially as AI systems become integral to critical aviation operations
Category	<Security>

Identifier	**REQ-SOL0447-FRD-PM03.0013**
Title	**Regulatory Compliance Features**
Requirement	AI systems shall comply with aviation regulations and standards
Status	<not applicable for CODA solution>
Rationale	Adherence to regulatory requirements is essential for the safe and legal operation of air traffic management systems, especially after a change in roles and responsibilities.
Category	<Functional>, <Safety>, <Security>, <Data>

Identifier	**REQ-SOL0447-FRD-PM03.0014**
Title	**Scalability and Adaptability**
Requirement	Systems shall be scalable and adaptable to accommodate future advancements in AI and changing operational needs
Status	<in progress>
Rationale	The ability to scale and adapt ensures that the technology remains effective in a dynamic and evolving aviation environment. Scalability ensures that the air traffic management systems can efficiently handle varying workloads, while Adaptability ensures that these systems can evolve to incorporate new technologies and adapt to changes in the aviation landscape. Both are essential

	for creating a resilient, efficient, and future-proof infrastructure for air traffic controllers in their planning and monitoring roles.
Category	<Functional>, <Safety>, <Adaptability>, <Performance>, <Design>

5.4 Standardisation between sectors, towers and/or CWPs

Identifier	**REQ-SOL0447-FRD-STD04.0001**
Title	**Controller Working Position Standardised Digital Assistant**
Requirement	The system shall standardize the functions done by CWP, in enroute or tower settings.
Status	<in progress>
Rationale	To effectively integrate this digital assistant into the CWP, several options are possible. A contextual window within the existing operational interface could provide seamless access to the assistant's functionalities, ensuring that controllers have uninterrupted access to critical information. Alternatively, a dedicated screen specifically for the assistant's outputs could offer a distinct and focused area for its insights and suggestions. Controller Working Position Standardised Digital Assistant could be used with notifications and alerts, a combination of visual, auditory, and haptic signals employed to suit different scenarios and controller preferences.
Category	<Functional>, <Safety>, <Security>, <Reliability>, <Performance>, <Design>, <Interface>, <HMI>,

5.5 Being monitored continuously by systems

Identifier	**REQ-SOL0447-STD-BMC05.0001**
Title	*Continuous Real-Time Monitoring of ATCO Activity and Mental State*
Requirement	**The system shall continuously monitor ATCO activity, specifically fixation locus, and assess mental states to infer intentions and support needs in real time.**
Status	<in progress>
Rationale	*This requirement aligns with the need for mutual transparency and explainability. Monitoring both activity and mental state enables the system to dynamically adapt support, fostering effective collaboration and shared situation awareness.*

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Category	<Functional>, <Performance>, <Safety>

Identifier	**REQ-SOL0447-STD-BMC05.0002**
Title	*Dynamic Allocation of Responsibilities*
Requirement	**The system shall dynamically allocate responsibilities between ATCOs and AI systems based on workload, environmental factors, and real-time demands.**
Status	<in progress>
Rationale	*Dynamic responsibility allocation ensures efficient resource utilization and response optimization. It accommodates adaptive task distribution, supporting effective responses in varying operational scenarios.*
Category	<Functional>, <Adaptability>, <Performance>

Identifier	**REQ-SOL0447-STD-BMC05.0003**
Title	*Emergency Mode Activation and Response*
Requirement	**The system shall activate an "Emergency Mode" and adapt responses accordingly in critical scenarios within a predefined timeframe.**
Status	<in progress>
Rationale	*This requirement addresses the need highlighted during workshops to respond differently in emergencies. It ensures swift adaptation to critical scenarios, minimizing potential impacts on safety and operations.*
Category	<Functional>, <Safety>, <Adaptability>

Identifier	**REQ-SOL0447-STD-BMC05.0004**
Title	*Legal Clarity and Responsibility Assignment*
Requirement	**The system shall provide clear delineation of legal responsibilities and liabilities associated with human interventions in dynamically adaptive systems, especially in automated functions like conflict detection.**
Status	<in progress>
Rationale	*Ensuring accountability and compliance in human-AI interactions, particularly in critical automated functions.*
Category	<Functional>, <Safety>, <Security>

Identifier	**REQ-SOL0447-STD-BMC05.0005**
Title	*Predictive Mental State Models*
Requirement	**The system shall employ predictive models analyzing historical traffic patterns to forecast potential mental states of air traffic controllers, providing proactive workload adjustments.**
Status	<in progress>
Rationale	*Predictive models allow the system to anticipate mental states, enabling pre-emptive adjustments to workload, enhancing performance, and reducing errors.*
Category	<Functional>, <Performance>

Identifier	**REQ-SOL0447-STD-BMC05.0006**
Title	*Transparent Decision Support*
Requirement	**The system shall provide clear and comprehensible visualizations explaining AI-generated suggestions or decisions, ensuring transparency and aiding controllers' understanding.**
Status	<in progress>
Rationale	*Transparent decision support fosters trust and acceptance of AI-driven decisions, empowering controllers to make informed judgments based on system suggestions.*
Category	<Design>, <Interface>

Identifier	**REQ-SOL0447-STD-BMC05.0007**
Title	*Collaborative Interface Design*
Requirement	**The system shall facilitate a user-friendly interface enabling effective collaboration between air traffic controllers and AI systems, allowing input, feedback, and influencing decision-making.**
Status	<in progress>
Rationale	*A collaborative interface encourages interaction and feedback from controllers, ensuring a smooth and harmonious collaboration between humans and machines.*
Category	<Interface>, <HMI>, <Design>

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Identifier	**REQ-SOL0447-STD-BMC05.0008**
Title	*Data Privacy and Ethical Compliance*
Requirement	**The system shall employ encryption, access controls, and anonymization techniques to protect sensitive biometric data, ensuring compliance with privacy regulations and ethical standards.**
Status	<not applicable for CODA solution>
Rationale	*Protecting sensitive data ensures the system maintains the privacy and confidentiality of controllers' biometric information, aligning with ethical guidelines and regulations.*
Category	<Security>, <Data>

5.6 Differences between different ATCOs roles

Identifier	**REQ-SOL0447-STD-DIF06.0001**
Title	*ATC procedures*
Requirement	Each ATCO role shall be supported by the system respecting the appropriate ATC procedures
Status	<in progress>
Rationale	ATCOs are expected to follow well established procedures. Supporting systems are expecting not to disrupt ATCOs way of working, in accordance with relevant procedures. Existing ATC procedures shall be reviewed for simplification and standardisation to ensure the applicability of the CODA concept.
Category	<Functional>

Identifier	**REQ-SOL0447-STD-DIF06.0002**
Title	*Supervisor Task Performance*
Requirement	The supervisor shall be able to get valuable information from the System, so to support their decision maling and ensure a safe application of the CODA system
Status	<in progress>
Rationale	CODA System is expected to communicate with other relevant stakeholders than ATCOs. Supervisors can benefit from information coming from the

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	system. The supervisor should oversee the work of ATCOs in the use of the new system to enable them to operate the system safely and effectively, minimizing the likelihood of operational errors.
Category	<Functional>, <Safety>, <Performance>

Identifier	**REQ-SOL0447-STD-DIF06.0003**
Title	*ATCOs Training*
Requirement	The ATCOs shall be trained in the use of the CODA system.
Status	<in progress>
Rationale	Training ensures that ATCOs become familiar with the features and functionalities of the CODA system. This will facilitate the integration of the new system into daily operational practices, leading to increased efficiency in managing air traffic, enhanced safety, optimised decision-making.
Category	<Functional>, <Safety>, <Performance>

5.7 ATCO-supporting tools

Identifier	**REQ-SOL0447-STD-AST07.0001**
Title	*Partial assistance of AI in controller tools*
Requirement	Controller tools with partial AI assistance shall anticipate and execute some aspects of the control task in nominal conditions with the human operator performing all remaining aspects of the control tasks
Status	<in progress>
Rationale	*No dramatic changes are foreseen in level 2 automation. More critical tasks will be performed by ATCO with support of automation enhanced tools using more accurate information. CD&R tools, vertical clearances could be considered in this category.*
Category	<Design>

Identifier	**REQ-SOL0447-STD-AST07.0002**
Title	*Conditional assistance of AI in controller tools*

Requirement	Controller tools with conditional AI assistance shall anticipate and execute most aspects of control task in nominal conditions, and the human intervenes upon system request.
Status	<in progress>
Rationale	*No dramatic changes are foreseen in level 3 automation, but higher level of intervention that in level 2 should be expected. Less critical tasks will be performed by the AI that will request the human intervention when needed. Coordination between centres, conformance monitoring and penetration detection tasks with trajectory resolution could be considered in this category.*
Category	<Design>

5.8 Adaptive interfaces

Identifier	**REQ-SOL0447-STD-ADP08.0001**
Title	**Supervision/Monitoring Interfaces**
Requirement	**The system shall provide clear and comprehensible visualizations explaining AI-generated suggestions or decisions, ensuring transparency and aiding controllers' understanding.**
Status	<in progress> OR <not applicable for CODA solution>
Rationale	Future interfaces might include holographic radar displays, offering a 3D visualization of air traffic. This could allow controllers to perceive and assess complex traffic scenarios more intuitively, with the system adjusting the level of detail based on traffic volume and controller workload.
Category	<Functional>, <Data>, <Design>, <Interface>, <HMI>,

Identifier	**REQ-SOL0447-STD-ADP08.0002**
Title	**Alarm Systems**
Requirement	**The system shall provide clear and comprehensible auditory signalizations explaining AI-generated suggestions or decisions, ensuring transparency and aiding controllers' understanding.**
Status	<in progress> OR <not applicable for CODA solution>
Rationale	Advanced auditory interfaces, such as 3D spatial audio alarms, could be used. These would provide directional cues to the source of a potential conflict, making it easier for controllers to pinpoint issues in a busy airspace, with alarm intensity adapting to the urgency of the situation.

Category	<Functional>, <Data>, <Design>, <Interface>, <HMI>,

Identifier	**REQ-SOL0447-STD-ADP08.0003**
Title	**Clearance Procedures**
Requirement	**The system shall provide clear and comprehensible clearance procedures based on voice recognition tools explaining AI-generated suggestions or decisions, ensuring transparency and aiding controllers' understanding.**
Status	<in progress> OR <not applicable for CODA solution>
Rationale	AI-driven voice recognition systems could automate routine clearances, allowing controllers to focus on more complex tasks. These systems would analyze traffic density and controller workload to decide when to offer automated assistance.
Category	<Functional>, <Data>, <Design>, <Interface>, <HMI>,

Identifier	**REQ-SOL0447-STD-ADP08.0004**
Title	**Grouping/Degrouping of Sectors**
Requirement	**The system shall provide clear and comprehensible grouping/degrouping sectors AI-generated suggestions or decisions, ensuring transparency and aiding controllers' understanding.**
Status	<in progress> OR <not applicable for CODA solution>
Rationale	AI algorithms could suggest optimal sector groupings in real-time, based on traffic patterns and controller capacity. For instance, in times of low traffic, the system might recommend degrouping sectors for more focused management, using predictive analytics to anticipate traffic surges.
Category	<Functional>, <Data>, <Design>, <Interface>, <HMI>,

6 Assumptions

6.1 Common assumptions for CODA solution

Several common assumptions that could be considered across different functions within the CODA solution:

- **Technology Reliability and Readiness**: An assumption is the reliability and readiness of the technological components forming the CODA solution. This includes the reliability of AI-driven systems, data integrity, and the adaptability of technologies to real-time air traffic scenarios.
- **Regulatory and Ethical Compliance**: Assumptions might revolve around compliance with existing aviation regulations, ethics and the adaptability of the CODA solution to accommodate evolving regulatory and ethical frameworks.
- **Safety Standards**: There's an assumption that the CODA solution maintains or enhances safety standards in air traffic management. This encompasses the reliability of AI systems in decision-making, minimizing risks, and preventing accidents.
- **Operational Integration**: Assumptions include the seamless integration of new technologies with existing infrastructure and operational processes. This encompasses interoperability between different systems and a smooth transition without disrupting ongoing operations.
- **User Acceptance and Training**: There's an assumption of user acceptance among ATCOs and stakeholders impacted by the CODA solution. It assumes adequate training programs and user-friendly interfaces for easy adoption.
- **Scalability and Flexibility**: The CODA solution assumes scalability to accommodate varying air traffic volumes and flexibility to adapt to future changes in air traffic management requirements without significant overhauls.
- **Performance and Efficiency**: Assumptions encompass the performance gains and operational efficiencies expected from the CODA solution. This includes assumptions about reduced delays, optimized routes, and improved overall efficiency in air traffic management.
- **Data Security and Privacy**: An assumption is that the CODA solution ensures robust data security and privacy measures, safeguarding sensitive information and complying with data protection regulations.
- **Cost-Effectiveness**: There's an assumption about the cost-effectiveness of implementing the CODA solution, considering factors such as initial investment, maintenance, and operational costs versus the benefits accrued.
- **Stakeholder Collaboration**: Assumptions might involve effective collaboration among various stakeholders, including industry players, regulatory bodies, and technology providers, to support the successful deployment and evolution of the CODA solution.

These assumptions underlie the foundation of the CODA solution, providing a framework for its development, implementation, and ongoing operational success within the air traffic management domain.

6.2 Specific assumptions for CODA solution

While formulating requirements for each topic, several specific assumptions could influence their design and implementation. Here are a few assumptions to consider for each topic:

6.2.1 Specific assumptions on Artificial Intelligence

- **AI development assumption**. The objective of CODA is to investigate the benefits of the AI-human teaming when the AI is aware of the current and future situation of the controller (mental state, tasks, tools) not the development of an AI for a specific use. AI simplification will be performed when needed.
- **AI in validation assumption.** When needed in validation the AI will be simulated through a human in the background.

6.2.2 Specific assumptions on planning and monitoring rather than active controlling

- **Human-AI Collaboration**. Effective collaboration between human controllers and AI systems is feasible and can lead to improved overall system performance. The assumption is that a well-designed collaboration between humans and AI can leverage the strengths of both, combining the adaptability and decision-making abilities of humans with the processing power and efficiency of AI.
- **Data Quality and Availability**. Sufficient and high-quality data are available for AI systems to make informed decisions. The successful implementation of AI in ATC assumes the availability of accurate and timely data for the algorithms to analyze and generate meaningful insights.
- **Continuous Technological Advancements**. Ongoing advancements in AI technology will continue to enhance the capabilities and reliability of AI systems in the ATC context. The shift assumes that technological progress will contribute to addressing challenges and improving the overall performance of AI in air traffic management.

6.2.3 Specific assumptions on being monitored continuously by systems

- **Technological Assumptions**: The requirements assume the availability and reliability of advanced monitoring technologies capable of continuously assessing ATCO activity and mental states in real time. Assumptions about the technological maturity and accuracy of these monitoring systems are implicit.
- **Data Accessibility and Quality**: The requirements assume access to high-quality data inputs for monitoring ATCO activity and mental states. The system's functionality relies on the availability of accurate and reliable data sources without significant interruptions or biases.
- **Integration and Compatibility**: Assumptions are made regarding the seamless integration of monitoring systems into existing air traffic control infrastructure and protocols. Compatibility with diverse systems and interfaces within the ATC environment is essential.

- **Human-AI Collaboration**: These requirements assume a cooperative and mutually beneficial relationship between ATCOs and AI systems. They presume a level of acceptance and willingness from ATCOs to engage with and trust the monitoring systems for effective collaboration.
- **Regulatory and Legal Frameworks**: The requirements assume compliance with existing regulatory frameworks and legal standards governing air traffic control operations. Assumptions about the system's ability to adhere to these standards and address liability and responsibility issues are implicit.
- **Performance and Scalability**: There's an assumption about the system's performance scalability, accommodating varying workloads, environmental conditions, and emergency scenarios without compromising real-time monitoring and adaptive responses.
- **Operational Conditions**: Assumptions regarding the operational conditions under which the system will function, including normal operational scenarios, emergency situations, and fluctuations in workload, are inherent in these requirements.

Acknowledging and documenting these assumptions is crucial as they can significantly impact the design, development, and successful deployment of the CODA solution.

7 References

7.1 Applicable documents

Project and programme management

[1] 101114765 CODA Grant Agreement

[2] SESAR 3 JU Project Handbook – Programme Execution Framework

7.2 Reference documents

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