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# Concept of Operations for AWARE


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## Abstract

This document describes the Concept of Operations (ConOps) for Achieving human-machine collaboration with artificial situational awareness (AWARE). This concept of operations is developed as a base for human-machine collaboration and situational awareness that will be used as support in execution of and monitoring of ATCO tasks. It proposes the monitoring and execution of ATCO tasks which could be assigned to AI in this project. This document will be useful to partners involved in the project as a basis for further research and reference in subsequent deliverables.

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# AWARE

ACHIEVING HUMAN-MACHINE COLLABORATION WITH ARTIFICIAL SITUATIONAL AWARENESS

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# 1 Executive summary

The AWARE project aims to advance human-machine collaboration in air traffic management by developing an Artificial Situational Awareness system. This system enhances the decision-making capabilities of ATCOs by providing timely, relevant support through artificial intelligence, allowing them to better manage complex air traffic scenarios.

Building on the SESAR project AISA, which successfully created a knowledge graph-based AI system to monitor traffic situations, AWARE introduces improvements by focusing on ATCO intent assessment, human-machine interface integration, and adaptable automation. The system helps ATCOs manage both critical and routine tasks, offering recommendations for conflict resolution, route optimisation, and task prioritisation based on real-time data and attention-tracking technologies.

Key performance outcomes expected from the AWARE system include:

- Increased capacity: The Artificial Situational Awareness system can have medium to high positive impact on en-route capacity, as ATCOs receive automation support for routine tasks and complex decision-making.

- Improved environmental impact: By optimizing flight routes and tasks, AWARE aims to provide low to medium reduction in en-route emissions.

- Enhanced safety: AWARE provides an additional safety net for ATCOs, helping prevent loss of situational awareness and reducing reliance on alert systems.

- Operational efficiency: The automation support can reduce ATCO workload and operational inefficiencies, leading to a low reduction in horizontal en-route flight inefficiency.

Moving forward, the AWARE project focuses on integrating explainable AI tools into ATCO workflows, ensuring that human oversight remains central to decision-making. The project will expand testing into more complex airspace scenarios and investigate the scalability of ASA across various flight phases. The next research phase will emphasize operational validation and stakeholder engagement, ensuring that the system meets SESAR standards and industry needs.

# 2 Introduction

## 2.1 Purpose of the document

The purpose of this document is to describe the work undertaken to develop the analysis of the current operational scenario settings in en-route operations and the expected future operational scenario settings as the basis for developing the AWARE concept. The current version sets the way for the forthcoming actions of the AWARE project. Nevertheless, revision of the AI-related Concept of operations will be necessary as knowledge on artificial intelligence increases.

## 2.2 Intended readership

The main audience of this Concept of Operations document is:

- SESAR Joint Undertaking,
- Air Navigation Service Providers (ANSPs),
- Air Traffic Controllers (ATCOs),
- Airspace Users,
- UAV Users,
- Air Traffic Management research community,
- Air Traffic Management system developers, and
- regulators in the field of aviation

## 2.3 Background

The AWARE solution builds on the SESAR project AISA, which developed an artificial situational awareness system using aeronautical data exchange models like AIXM (Aeronautical Information Exchange Model) and FIXM (Flight Information Exchange Model). This system created a knowledge graph of the traffic situation, enabling a reasoning engine to generate insights and automate monitoring tasks. Enhanced with machine learning modules for predicting future states, the proof-of-concept was tested in human-in-the-loop simulations. Results showed the system's situational awareness was comparable to that of human operators in en-route air traffic control (ATC), providing an additional safety net by automating 47 tasks and suggesting actions for air traffic controllers (ATCOs).

However, the system faced challenges in collaborating with ATCOs due to:

- Lack of awareness of ATCOs' intents and goals, resulting in untimely support.
- Ineffective human-machine interface (HMI) to convey information.
- Inflexibility in adjusting the level of support.




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A major barrier to effective human-machine collaboration in air traffic management (ATM) is the machine's inability to understand ATCOs' needs, providing appropriate information or actions at the right time. AISA highlighted this issue by exploring shared situational awareness but failed to address the challenge of inputting to ATCOs without disrupting their workflow. This disconnect indicates that while humans understand machine capabilities, machines lack reciprocal understanding of human operators. In simple interactions, this is manageable, but in complex environments with diverse traffic, it is crucial for machines to understand humans to achieve effective collaboration.

The ambition is to expand the artificial situational awareness system's functionality to provide timely and relevant support by assessing ATCOs' intents and goals. This support can assist ATCOs in tasks they intend to perform and autonomously execute tasks outside their immediate attention. Developing a combination of ML and non-ML tools will determine the feasibility of such supportive actions. The goal is for ATCOs to set the desired level of support from the AI, maintaining situational awareness while avoiding complacency and the out-of-the-loop effect.

Enhancing the Artificial Situational Awareness (ASA) system involves expanding its capabilities with new knowledge-graph schemas, vocabulary, and rule-based knowledge. Implementing an effective HMI at the controller's working position will facilitate information sharing and enable ATCOs to select the required level of automation support, ensuring the human remains central to the system.

## 2.4 Structure of the document

This Concept of Operations document is structured as follows:

1. Executive Summary of the document,
2. Introduction of the document,
3. Concept outline. This chapter includes a problem statement which presents the problem addressed by the project, Concept description and operational scenarios which details the description of the AWARE project's solution that aims at solving the problem described in the problem statement. Expected performance outcomes and key assumptions are also detailed in this chapter.
4. Proposed SESAR solutions. This chapter defines the proposed solutions that could be addressed by future application oriented exploratory research projects.
5. Plan for next R&I phase. This chapter describes what future activities should be carried out in the future to continue this R&I endeavour along with what activities that could not be carried out due to the limited scope of the project, should be addressed in the next R&I phase.
6. References. This chapter lists the main references the Concept of Operations document shall comply to or on which it has been built.

## 2.5 Glossary of terms

| Term | Definition | Source of the definition |
|---|---|---|
| AI ASSISTANT APPLICATION (AAA) | The AI Assistant Application (AAA) supports ATCOs by providing real-time insights, automating tasks, and enhancing decision-making through data integration and machine learning. | Part B of the AWARE project proposal document ([1]) |
| ARTIFICIAL SITUATIONAL AWARENESS (ASA) SYSTEM | Artificial Situational Awareness system that uses AI to enhance ATCOs' situational awareness by automating monitoring, predicting traffic, and assisting decision-making. | Part B of the AWARE project proposal document ([1]) |
| PRESCRIPTIVE AVIATION | Capability to identify a set of measures to avoid the problem in aviation | SESAR JU SRIA document ([4]) |
| OUT-OF-THE-LOOP EFFECT | The out-of-the-loop effect occurs when automation reduces human engagement, leading to decreased situational awareness and impaired decision-making during critical tasks. | MINIMA Project, D1.1 State of the Art Report ([3]) |

**Table 1. Glossary of terms**

## 2.6 List of acronyms

| Acronym | Definition |
|---|---|
| AAA | AI Assistant Application |
| ADS-B | Automatic Dependent Surveillance-Broadcast |
| AI | Artificial Intelligence |
| AIXM | Aeronautical Information Exchange Model |
| ANSP | Air Navigation Service Provider |
| ASA | Artificial Situational Awareness |
| ATCO | Air Traffic Control Officer |
| ATM | Air Traffic Management |
| ATSEP | Air Traffic safety electronics personnel |
| CPDLC | Controller-Pilot Data Link Communications |



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| Acronym | Definition |
|---|---|
| EUROCONTROL | European Organization for the Safety of Air Navigation |
| FAA | Federal Aviation Administration |
| FIXM | Flight Information Exchange Model |
| HMI | Human-Machine Interface |
| JU | Joint Undertaking |
| KG | Knowledge Graph |
| KPA | Key Performance Area |
| LoA | Letter of Agreement |
| ML | Machine Learning |
| OOTL | Out-of-the-loop |
| QoS | Quality of Service |
| R&I | Research and Innovation |
| RDF | Resource Description Framework |
| RFL | Requested Flight level |
| SESAR | Single European Sky ATM Research |
| SRIA | Strategic Research and Innovation Agenda |
| STCA | Short Term Conflict Alert |
| SUP | Supervisor |
| TRL | Technology Readiness Level |
| UAV | Unmanned Aerial Vehicle |

**Table 2. List of acronyms**

# 3 Concept outline

## 3.1 Problem statement

For the development of the AWARE solution, the following list of challenges of the current ATM concept of operations have been identified:

- Necessity for system-wide performance enhancements in capacity, flight efficiency, environment and safety (airborne operations optimization),
- Necessity for solutions to mitigate negative impacts of automation on ATCOs (complacency, distraction and the out-of-the-loop effect) [3],
- High-level need for trustworthy AI powered ATM environment [4],
- Need for AI systems for prescriptive aviation (capacity, cost efficiency and environmental impact balancing) [3],
- Necessity for human-AI collaboration via digital assistants [3], and
- Necessity for AI Improved datasets for better airborne operations [3]

According to the SESAR JU's Strategic Research and Innovation Agenda (SRIA) document, the outcomes and performance objectives that are expected from future AI systems for aviation are listed in the following subsections.

## 3.2 Concept description and operational scenarios

AWARE is developing a proof-of-concept AI Assistant Application to showcase the Artificial Situational Awareness solution, which aids ATCOs by identifying and supporting their goals. The ASA system, created during the AISA project, uses aeronautical information models to build a knowledge graph of the traffic situation, enhancing it with rule-based knowledge and a reasoning engine for semantic understanding. However, it currently cannot assess ATCOs' goals. To enable effective human-machine collaboration, the system will track ATCOs' attention and human-machine interfaces to infer their intent and determine supportive actions. The system will assist ATCOs either by helping with tasks they are focused on or managing tasks outside their immediate attention. ATCOs can dynamically control the level of support the system provides.

### 3.2.1 Operational/Technical context

AWARE's approach focuses on developing a proof-of-concept AI Assistant Application to demonstrate the Artificial Situational Awareness solution, which supports ATCOs by identifying and aiding in their goals (Figure 1). The ASA system (green block in Figure 1), developed during the AISA project, uses aeronautical information exchange models to create a knowledge graph representing the traffic situation, converted to the Resource Description Framework. This graph, enhanced with rule-based knowledge and a reasoning engine, builds a semantic understanding of the traffic situation but cannot assess ATCOs' goals and actions. To enable effective human-machine collaboration (blue block in Figure 1), the system will track ATCOs' attention and human-machine interfaces. By contextualizing




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this information within the traffic situation, the system will infer ATCOs' intent and determine supportive actions.

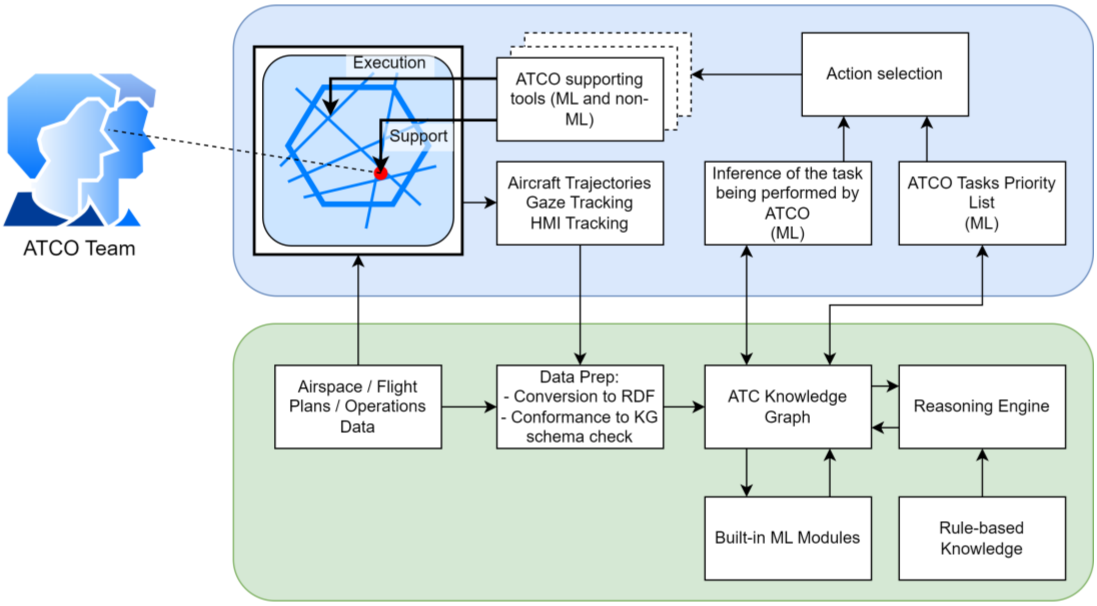


**Figure 1. AI Assistant Application**

The system will explore two ways of assisting ATCOs:

- Supporting tasks currently under active attention, such as conflict detection and resolution, trajectory monitoring, and response to pilot requests; and
- Managing tasks outside their immediate attention, such as proactively identifying emerging conflicts in peripheral sectors, alerting to aircraft nearing sector boundaries requiring coordination, or detecting unacknowledged pilot messages.

This distinction allows the system to balance between reinforcing focused task execution and improving ATCO's peripheral situational awareness. Adaptability is ensured as ATCOs can control the process by dynamically selecting the number of actions the system provides per unit of time. The following sections detail the concepts and methodologies involved in this approach.

### 3.2.1.1 Attention and HMI tracking

The Artificial Situational Awareness integrates attention and HMI tracking technologies to enhance the situational awareness of ATCOs. This system ensures that ATCOs can manage complex air traffic scenarios while maintaining a high level of performance and safety. The system achieves this through a combination of passive eye tracking, interaction monitoring, and correlation of gaze and input data with HMI elements, as illustrated in Figure 2.

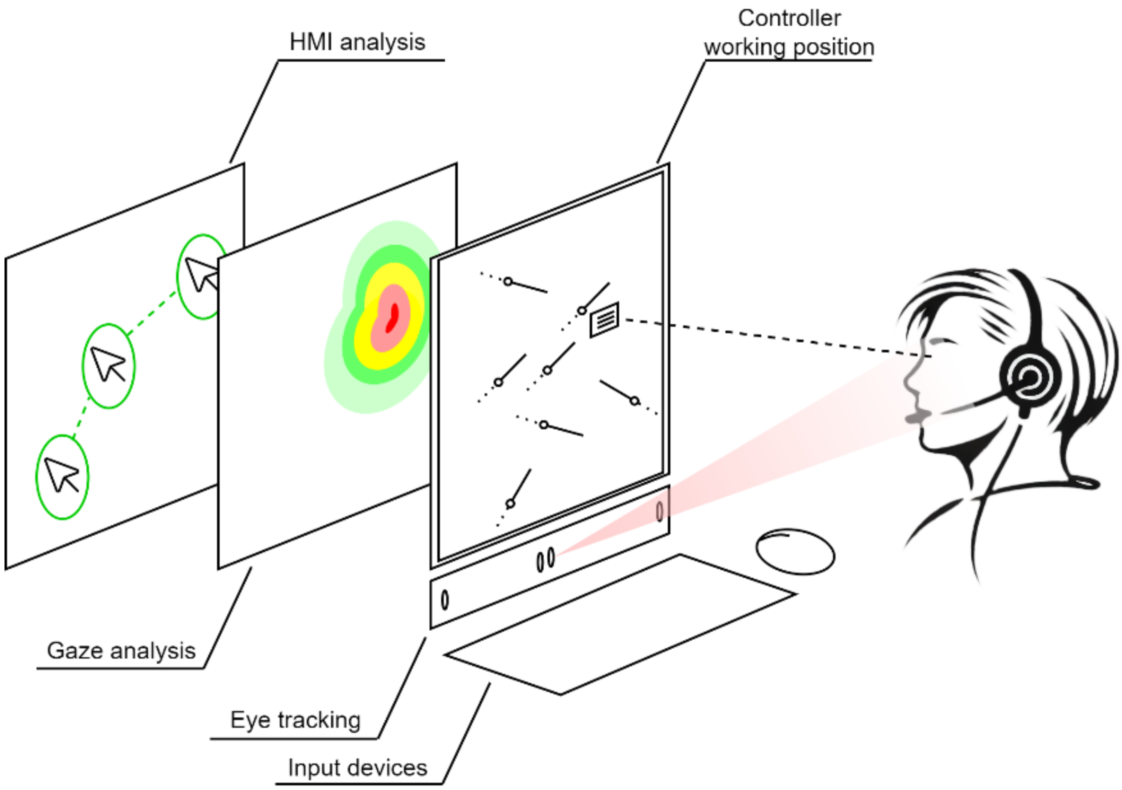


**Figure 2. Attention and HMI tracking technologies used in the ASA system**

ATCO intent, in this context, refers to the inferred cognitive goal or anticipated action of an air traffic controller based on their gaze behaviour, interaction with human-machine interface (HMI) elements, and overall task context. It is not a direct measurement, but a probabilistic assessment derived from observable patterns in eye movement, manual inputs, and decision-making workflows. Understanding ATCO intent allows for predictive support, enabling the system to recognize whether a controller is resolving a conflict, conducting Quality of Service (QoS), or responding to a pilot request.

The current implementation does not include the use of voice communications for intent recognition. Instead, the system focuses on correlating gaze and interaction data with structured communication inputs available via Controller-Pilot Data Link Communications (CPDLC). Where applicable, CPDLC message activity (e.g. uplink or downlink events) will be temporally aligned with gaze data and interface interactions to support the inference of ATCO intent. Future developments, possibly in follow-up projects, may consider integrating voice communication analysis to complement this approach.

To translate gaze data into ATCO intent, the system processes eye-tracking information through multiple intermediate steps. Initially, fixation duration, saccadic movements, scanning pattern, and gaze transitions between interface elements and flights (including label) are analysed to detect attentional focus areas. These raw gaze data points are then mapped onto predefined HMI elements, such as aircraft labels, flight paths, and control panels. The information about the interaction with the HMI will be extracted from the simulation data (from Polaris). By comparing gaze sequences to known task structures, the system can classify whether an ATCO is engaging in routine monitoring, resolving a conflict, or executing a planned task. Additionally, gaze clustering techniques help to identify sustained attention on specific airspace regions, which can signal increased cognitive processing related to potential traffic conflicts.

A rule-based system has been developed to systematically define how different gaze behaviours and HMI interactions translate into specific ATCO intentions. This structured approach follows an "if-then" logic, where observed actions such as gaze fixation on aircraft labels, cursor movements, and communication inputs are mapped to corresponding intentions, such as conflict detection, resolution, or routine flight management. By using predefined rules and conditions, the system ensures a standardized interpretation of ATCO behaviour, reducing ambiguity in intent classification and enhancing predictive accuracy.

This rule-based framework also integrates multiple behavioural indicators to refine intention assessment. For instance, if an ATCO scans multiple aircraft labels in quick succession while adjusting a speed vector, the system interprets this as conflict detection rather than routine monitoring. Additionally, optional conditions—such as the use of measurement tools or probing functions—help differentiate between standard procedural tasks and higher-complexity decision-making processes. By structuring intent recognition in this way, the system improves its ability to anticipate controller actions and provide tailored decision-support recommendations.

Extended fixations on critical airspace zones may indicate high monitoring activity, whereas gaze shifts followed by cursor interactions suggest active decision-making. Sequential gaze movements between aircraft and conflict resolution tools can signal an intent to adjust aircraft separation or reroute a flight.

Beyond gaze tracking, the system refines its intent assessment by integrating cursor movements and keyboard inputs. For example, if an ATCO fixates on an aircraft label and subsequently moves the cursor toward a coordination tool, the system interprets this as intent to modify flight parameters. Similarly, repeated shifts between different interface elements may indicate workload management or uncertainty, prompting adaptive system support. By combining these interaction data with historical task patterns, the system builds a dynamic model of ATCO intent, allowing for more accurate recognition of operational priorities and potential support needs.

#### 3.2.1.2 Task identification and prioritization

The ASA system provides a framework for task identification and prioritization to assist ATCOs in managing the safe and efficient flow of air traffic. By utilizing a combination of rule-based systems and knowledge graphs (KG), the ASA system identifies and prioritizes tasks, ensuring that critical operations are handled effectively and with minimal delays.

Rule-Based Knowledge for Task Identification: The ASA system defines a set of rules to detect the tasks that an ATCO is currently managing. These rules are based on operational protocols, traffic conditions, and environmental factors, enabling the system to determine what actions the ATCO should be performing at any given moment. For example, certain thresholds for aircraft separation or altitude changes trigger specific tasks, such as conflict resolution or issuing new instructions.

Reasoning over knowledge graphs: The system employs reasoning over a knowledge graph, which contains detailed information about ongoing flights, airspace conditions, and ATCO actions. By cross-referencing the current state of traffic with predefined operational rules, the system can identify active tasks being performed by the ATCO. This process helps in understanding the dynamic environment that the ATCO is working in and ensures all relevant tasks are captured in real-time.

Prioritization of ATCO Tasks: The conceptual process is shown in Figure 3. Once tasks are identified, the ASA system applies task prioritization algorithms to ensure that the most critical operations are addressed first. The system prioritizes tasks based on their impact on the safe and efficient flow of traffic. For example, conflict detection and resolution tasks will have a higher priority than routine handoff tasks when traffic density is high. This hierarchical prioritization is presented in a visual format, allowing ATCOs to manage their workload based on the urgency and importance of each task.

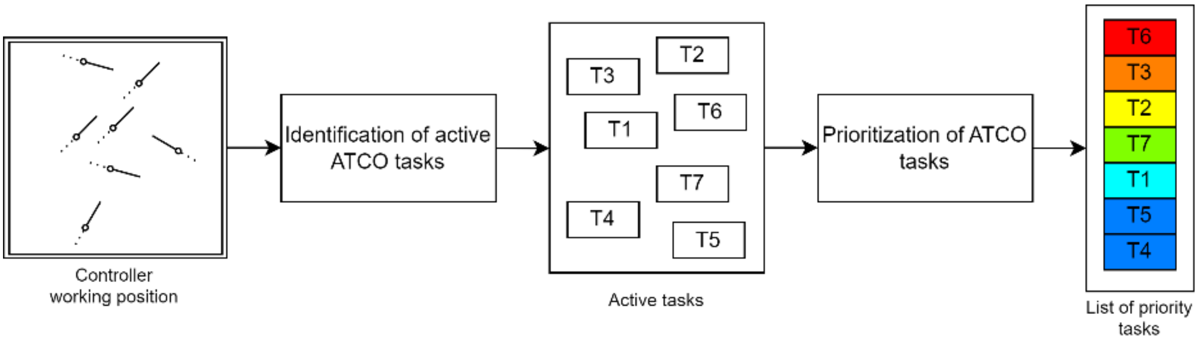


**Figure 3. Task identification and prioritization process flow**

Task identification and prioritization process flow, as shown in Figure 3:

1. Task Identification: The system analyses the ATCO's current working position and identifies all active tasks, such as monitoring flight trajectories, issuing clearances, and managing conflicts.

2. Task Listing: Active tasks are listed based on real-time data from the traffic situation and ATCO interactions. Each task is continuously monitored to account for any changes in air traffic conditions.

3. Prioritization: Tasks are prioritized based on safety and traffic efficiency criteria. Figure 4 shows the task priority matrix used to prioritize tasks based on their safety impact and time it takes to do those tasks. Higher-priority tasks, such as conflict resolution, are flagged in red, while lower-priority tasks, such as routine communications, are marked with lower priority colours. This system ensures that critical issues are addressed promptly while less urgent tasks are completed in due course.

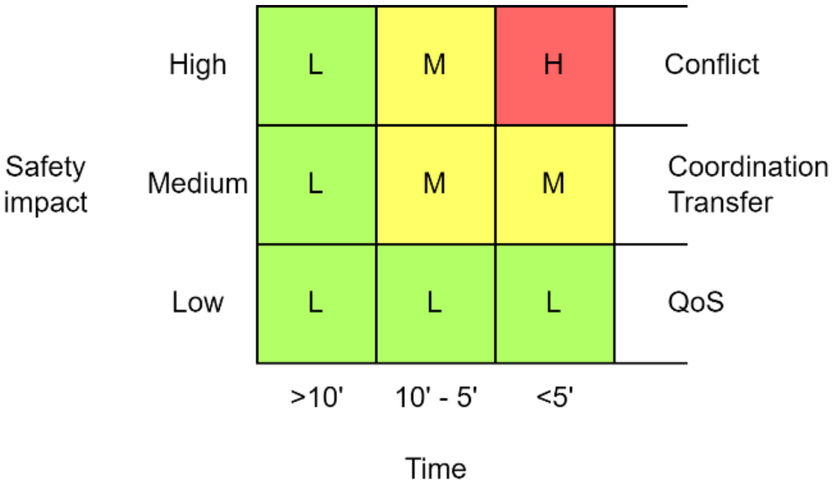


**Figure 4. Task priority matrix**

#### 3.2.1.3 ATCO intent assessment

The ASA system integrates multiple data streams to assess the current intent of the ATCO and ensure they are maintaining focus on the highest priority tasks. This assessment combines insights from the ATCO's attention and HMI tracking, and active task identification, providing an assessment of their intent. The goal is to prevent a loss of situational awareness and ensure that critical tasks are prioritized correctly. Figure 5 shows a simplified illustration of the ATCO intent assessment process.

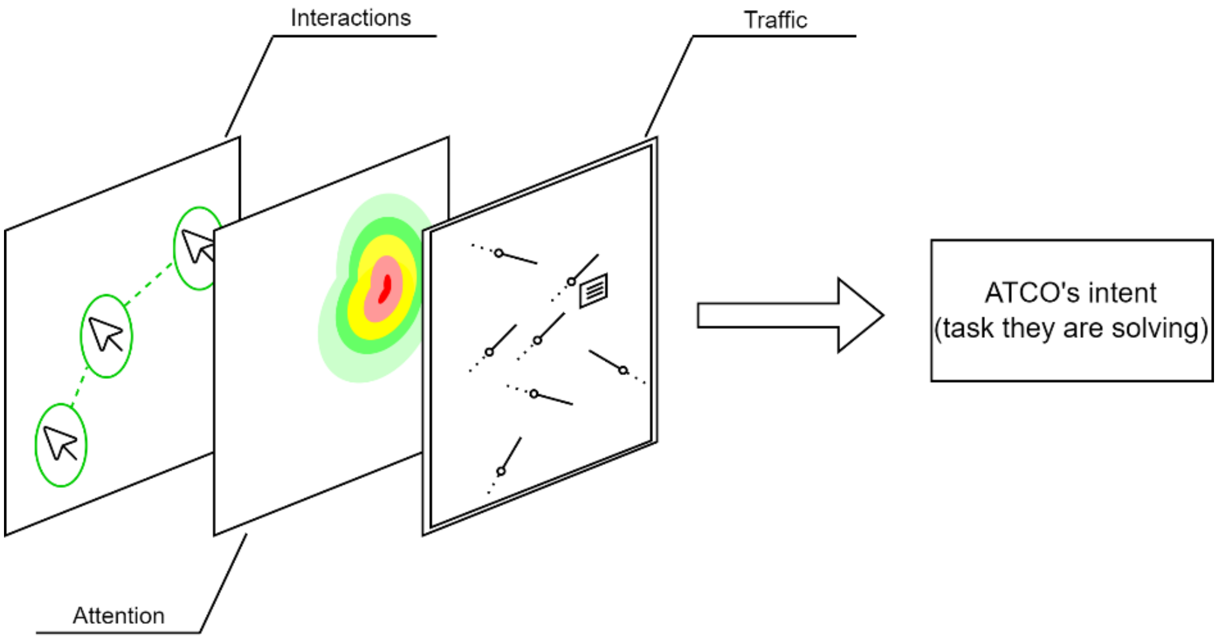


**Figure 5. ATCO intent assessment visualisation**

The ASA system continuously collects data on the ATCO's attention (via gaze tracking), their interactions with the human-machine interface (e.g., mouse clicks, keyboard inputs), and the list of active tasks they are managing. By utilizing this information, the system gains a real-time understanding of which elements the ATCO is focusing on and how this aligns with the operational tasks they need to perform.

A machine learning model trained on historical data and expert knowledge is used to predict the most likely task the ATCO is performing at any given moment. The model considers the combination of gaze focus, recent interactions with the HMI, and the context of active tasks. Importantly, this is an explainable machine learning model, meaning that its decisions are transparent and can be interpreted by the ATCO, supervisors, and safety managers. This ensures that the system can provide clear reasoning behind its predictions, enhancing trust and usability.

Once the system identifies the most likely task being performed by the ATCO, it cross-references this with the list of active tasks and their assigned priorities. If the ATCO is working on the highest priority task, the system confirms that this is optimal, and no further action is needed.

However, if the system detects that the ATCO is focusing on a lower-priority task – while higher-priority tasks remain unattended – this may indicate a loss of situational awareness and the ATCO being OOTL (out-of-the-loop). In such cases, the system can issue a gentle alert or suggestion, prompting the ATCO to refocus on the more critical tasks. This feature ensures that controllers remain aware of evolving traffic conditions and do not inadvertently spend too much time on less urgent matters.

It is recognised that behavioural patterns such as gaze distribution, interaction habits, and prioritisation tendencies may differ among ATCOs depending on training background, operational context, and national procedures. The behavioural models developed during the project are initially based on a limited participant pool and therefore may not fully reflect the broader ATCO population. Broader validation efforts involving diverse ATCO profiles will be necessary in subsequent phases to assess representativeness and improve generalisability.

#### 3.2.1.4 ATCO supporting tools

The ASA system incorporates AI-based supporting tools that assist ATCOs in both managing high-priority tasks and autonomously executing lower-priority tasks, as shown in Figure 6. These tools are designed to enhance the safety and efficiency of air traffic management by either directly supporting ATCOs or autonomously managing less critical tasks while keeping the controller always informed.

The ASA system provides direct support to ATCOs by assisting with critical tasks through real-time suggestions and advice. One of the key areas where this is particularly valuable is conflict detection. The AI-based tools continuously monitor the airspace for potential conflicts between aircraft and provide early warnings to the ATCO. This enables the controller to take proactive steps before the situation escalates. Furthermore, the system also aids in conflict resolution by offering advice on potential solutions such as heading changes, altitude adjustments, or speed variations, ensuring conflicts are resolved efficiently while maintaining safety standards. In addition to conflict management, the AI assistant contributes to Quality of Service (QoS) improvements by suggesting optimal direct routes or recommending continuous climbs/descends to Requested Flight Levels (RFL) when they become available, helping to streamline operations and improve fuel efficiency.

Another direct ATCO support tool of the ASA system is its ability to manage flight transfers. The AI identifies flights that are ready for handover to another controller or sector and suggests any actions required to make these flights transfer-ready, such as verifying compliance with Letters of Agreement (LoA). This proactive support reduces the manual workload for controllers and ensures that handovers occur smoothly. Additionally, the AI assistant plays a vital role in coordination, both within the ATCO's own unit and between different sectors or units. It provides solutions and suggestions to facilitate smooth coordination, improving the overall efficiency of the air traffic management system.

Alongside direct support, the ASA system is designed to potentially autonomously execute certain lower-priority tasks under pre-defined conditions, with the objective of reducing ATCO cognitive load. Examples of such tasks may include managing flight transfers or suggesting direct routes, but the criticality of each task will depend on the specific traffic context and operational environment. At this stage, no feedback from ATCOs has been collected regarding the classification of these tasks or their delegation to the AI system. The current categorisation remains conceptual and will be validated through human-in-the-loop testing in future project phases. Importantly, any autonomous actions proposed by the system will be constrained by operational and procedural safeguards. Issuing clearances, for instance, will not be performed by the AI without appropriate authority delegation mechanisms in place. The controller remains the final decision-maker, and the system will maintain ATCO-in-the-loop confirmation or notification depending on task priority and rules of delegation.

Responsibility for safety-critical outcomes will remain with the human ATCO unless explicitly transferred through future regulatory or operational frameworks, which are beyond the scope of the AWARE project. The system's autonomous functionalities will be evaluated for safety and acceptability as part of the project's validation activities, but any formal allocation of liability would require coordination with regulatory bodies in subsequent initiatives.

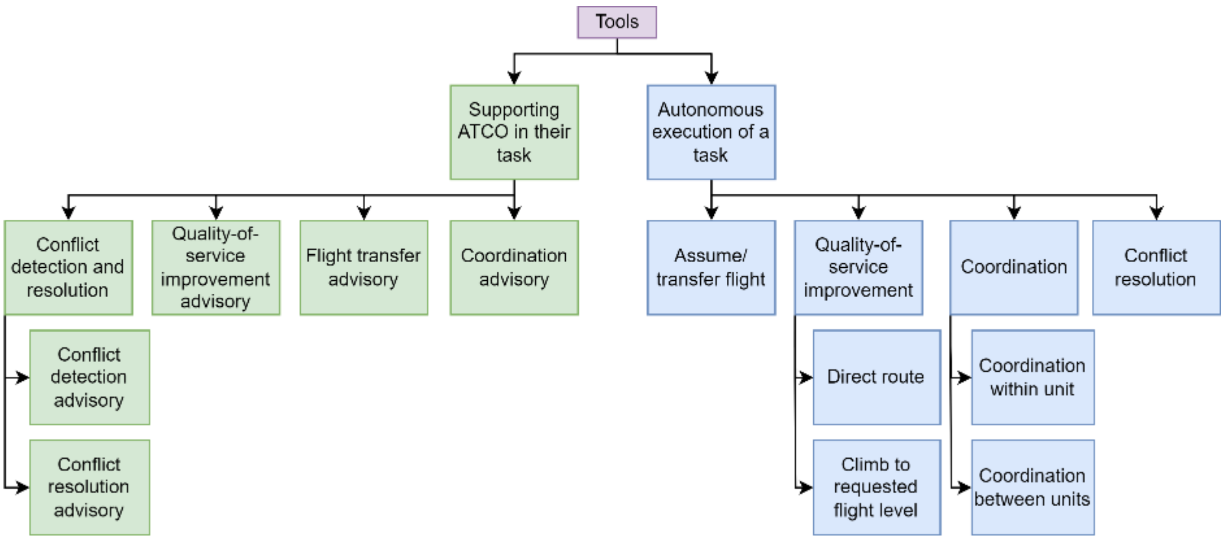


**Figure 6. ATCO supporting tools**

Workflow Integration of the ATCO supporting tools:

- Priority Queue Management: The AI assistant organizes tasks into a priority queue, ensuring that high-priority tasks are presented to the ATCO for manual intervention. Lower-priority



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tasks can be executed autonomously by the AI, but the ATCO is always kept in the loop and can intervene if necessary.

- Task Execution Support: As shown in Figure 7, the AI assistant operates alongside both the executive controller and the planning controller, supporting them with task execution. For high-priority tasks (Task 1), the system provides suggestions and monitoring, while for lower-priority tasks (Task 2 and below), the AI assistant autonomously manages them, updating the ATCOs on actions taken.
- ATCO Notifications for Autonomous Actions: Whenever the AI assistant autonomously executes a task, it provides an immediate indication to both the executive and planning controllers about the action performed. This ensures that both ATCOs are informed about the system's activities, maintaining full situational awareness and allowing for seamless collaboration between human operators and the AI assistant.

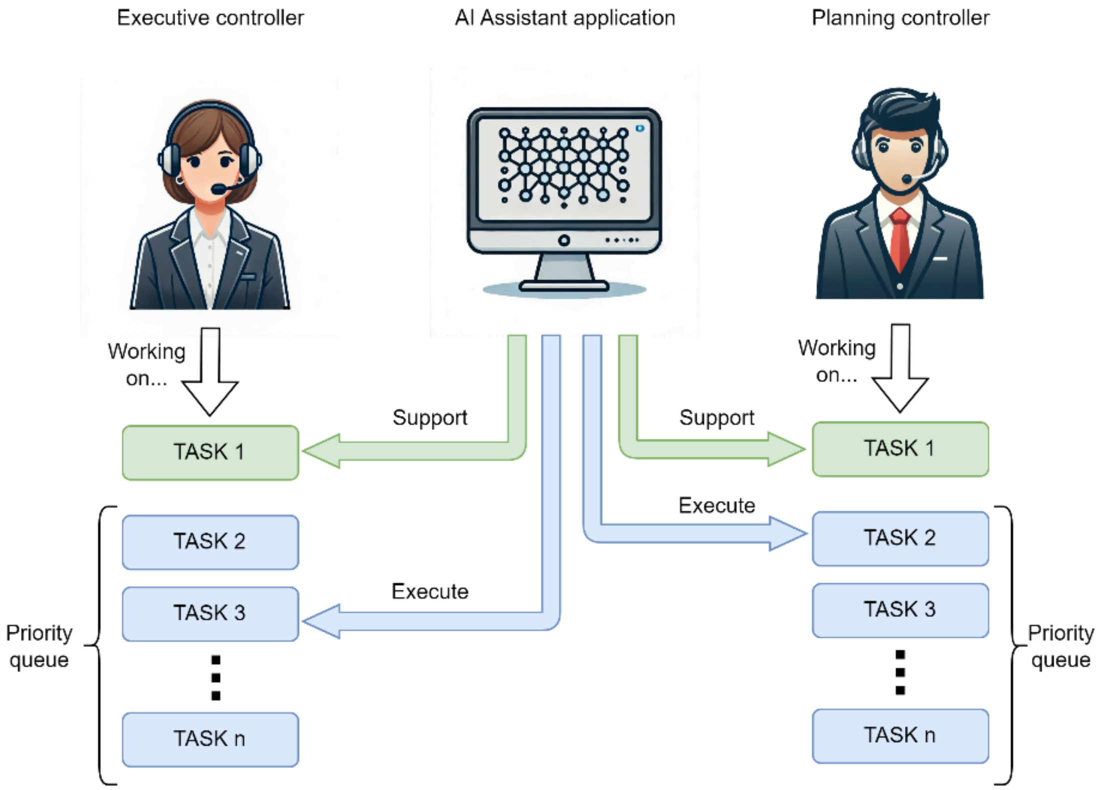


**Figure 7. Workflow integration of the ASA system supporting ATCOs**

### 3.2.1.5 Situational Awareness and Out-Of-The-Loop Effect

In a highly-automated en-route control centre the controller's role would shrink from continuous tactical intervention to long stretches of supervisory monitoring. Over time this shift can trigger complacency, i.e. an unjustified, "excessive trust in system ability" that lowers vigilance and situational awareness; distraction/under-attention, i.e. the mind wanders because the task load is too low to keep it engaged; and the broader out-of-the-loop (OOTL) effect, in which skills decay and the ATCO becomes unfamiliar with the system states that matter most in an emergency. SESAR research has catalogued the mechanism: increased automation "can reduce vigilance, create unjustified, excessive trust ... and lead to a loss of operator situation awareness," a cluster of difficulties known collectively as OOTL [3]. Neuro-ergonomic analysis in the STRESS project adds that "loss of skill, poor feedback and complacency may all contribute to the 'out-of-the-loop' problem" when mode transitions or failures occur [7].

For the AWARE concept, added value is expected primarily in high-complexity traffic scenarios, where cognitive demand increases and the risk of SA degradation is elevated. In contrast, in low-complexity situations, the ATCO's situational awareness is typically sufficient without requiring substantial intervention by the ASA system. The AI assistant is thus designed to adapt its level of support to traffic conditions, remaining minimally intrusive in simpler scenarios while offering higher-value support under higher workload.

For en-route ATC these effects must be mitigated because a controller who is cognitively disengaged may overlook subtle conflict cues, react too slowly to unexpected aircraft behaviour or automation failures, and thus jeopardise safety. AUTOPACE project, which looked specifically at the 2050 en-route environment, warns that OOTL poses "serious performance drawbacks … especially in case of automation fail," and therefore future ATCOs "should be trained" and systems redesigned to keep them mentally in the loop [8]. Without such counter-measures—adaptive automation that re-engages the operator, transparent feedback channels, psychophysiological vigilance monitors and targeted competency training—the promise of higher capacity and efficiency could be offset by rarer but more severe safety breakdowns when the machine hands back control under time pressure.

To prevent such risks, AWARE adopts several safeguards including adaptive automation principles, transparency in system actions, and ATCO-in-the-loop notifications. Regulatory oversight and operational procedures will define the boundaries of autonomous system actions and ensure that ATCOs remain the responsible decision-makers. Future regulatory developments will also help define how cognitive engagement, authority delegation, and system monitoring requirements are implemented in high-complexity environments to prevent loss of SA.

Figure 8 illustrates two scenarios that show how air traffic controllers manage tasks based on the complexity of traffic and their situational awareness (SA). In air traffic control, maintaining optimal situational awareness is crucial, particularly when traffic complexity increases. The left side of the figure represents a high complexity traffic scenario, while the right side shows a lower complexity environment.




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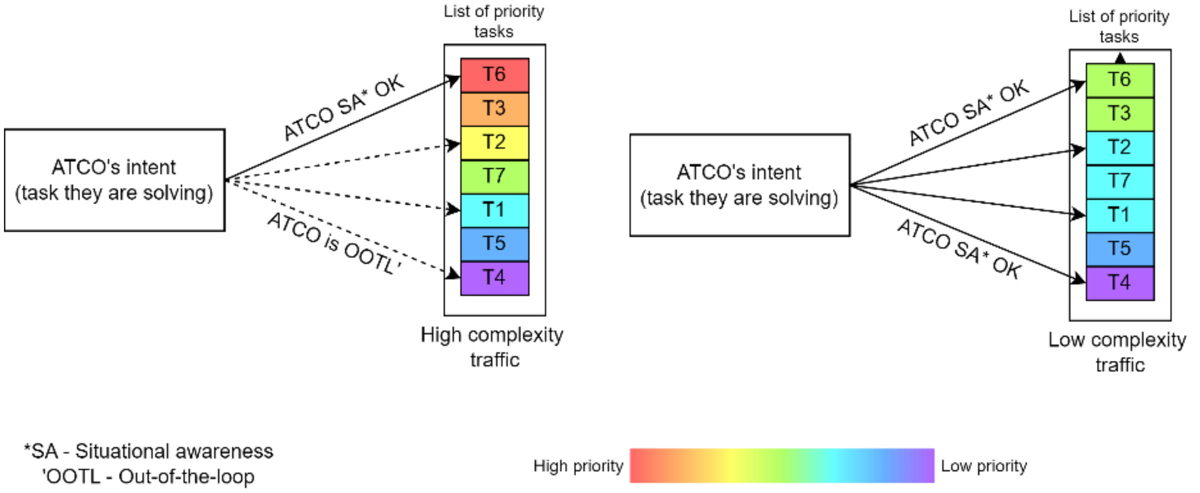


**Figure 8. ATCO Intent Assessment and Task Prioritization**

In the high complexity traffic scenario, the ATCO is presented with a list of priority tasks. Labelled from T1 to T7, tasks are ordered by priority, with the higher-priority tasks in warm and lower-priority tasks in cooler colours. Under these demanding conditions, the ATCO's Situational Awareness (SA) may degrade, leading to degraded Situational Awareness or Out-of-the-Loop (OOTL) effect. This is indicated by the dashed lines connecting the task list to the "OOTL" label.

Out-of-the-Loop effect occurs when the ATCO becomes detached from decision-making due to over-reliance on automation or task overload. It is important to note that OOTL in this context does not imply complete disengagement or transfer of authority. Rather, it highlights the cognitive challenge of maintaining attention across multiple dynamic tasks. AWARE's architecture incorporates transparency mechanisms, notification policies, and system feedback designed to counteract OOTL tendencies. The objective is to support ATCOs without inducing automation over-reliance or deskilling. In air traffic management, this state can be dangerous, as it reduces the ATCO's ability to respond effectively to unexpected events. When OOTL, the ATCO may struggle to prioritize tasks or intervene in critical situations, leading to delays or errors. High-complexity scenarios increase the risk of OOTL, making it essential to implement systems that help operators maintain Situational Awareness and remain actively engaged in decision-making.

On the other hand, Situational Awareness refers to an individual's ability to perceive, understand, and anticipate critical elements in their environment, enabling effective decision-making. In air traffic control, SA is crucial for ATCOs to monitor aircraft positions, assess potential risks, and manage traffic flow. High SA allows controllers to stay in-the-loop and foresee potential issues, ensuring safe and efficient airspace management. Maintaining SA requires continuous attention and the ability to process complex, dynamic information, especially in high-stress or high-complexity situations.

In a lower complexity traffic scenario, the ATCO deals with fewer or less demanding tasks. In these conditions, ATCO's Situational Awareness is more easily maintained, as indicated by the solid line labelled "ATCO SA OK." In this state, the ATCO remains fully engaged or in-the-loop, effectively managing and prioritizing tasks. There is less risk of overload or task mismanagement, allowing for smoother and more efficient operations.

The figure emphasizes the importance of Situational Awareness in air traffic control, particularly in scenarios of varying complexity. As the complexity of traffic increases, the likelihood of an ATCO losing track of tasks and becoming OOTL grows. In such situations, critical tasks may be overlooked or not addressed promptly, posing potential risks to flight safety. On the other hand, in less complex situations, the ATCO's ability to maintain control and manage tasks effectively improves significantly, reducing the chances of mismanagement.

### 3.2.1.6 ASA system reasoning engine

The reasoning engine in the ASA system integrates a rule-based knowledge system and machine learning modules to support ASA for ATCOs. The rule-based system is implemented using the datalog format, which defines monitoring tasks derived from the AISA project and adapted for AWARE. Currently, approximately 57 tasks are defined, although the list of tasks will be expanded. These tasks use logical rules to verify specific conditions in air traffic data, such as checking whether an aircraft maintains flight level. An example rule is provided in the datalog format shown in Figure 9, where temporal logic is applied to compare consecutive timestamps and determine if an aircraft's vertical rate remains zero, indicating FL maintenance.

```
# 5.1.3 Check that aircraft is maintaining FL
[?flight2, :isMaintainingFL, ?indicator] :-
   # Identify consecutive timestamps
   [?prevT, :next, ?currT],
   # Bind flights at each timestamp
   [?prevT, :flight, ?flight1],
   [?currT, :flight, ?flight2],
   # Extract the same flights only
   [?flight1, fx:aircraftIdentification, ?flightID],
   [?flight2, fxfx:aircraftIdentification, ?flightID],

   # Extract previous and current elements for the flight at each timestamp
   [?flight1, :currentElement, ?prevElement],
   [?flight2, :currentElement, ?currElement],

   # Extract previous and current levels and vertical rate
   [?prevElement, fx:point4D, ?prevPoint4D],
   [?prevPoint4D, fx:level, ?level],
   [?currElement, fx:point4D, ?currPoint4D],
   [?currPoint4D, fx:level, ?level],
   [?currElement, fx:extension, ?verticalRate],

   BIND(
      IF(
         ?verticalRate = 0,
         1,
         0
      )
      AS ?indicator
   ).
```

**Figure 9. Example rule of ASA system's reasoning engine**

The machine learning component is expected to complement rule-based reasoning by addressing tasks that require pattern recognition, anomaly detection, or probabilistic inference, such as predicting deviations from expected flight behaviour. The ML models under consideration include supervised learning approaches for trajectory prediction and unsupervised methods for detecting anomalies in air traffic patterns. The integration of both approaches ensures a balance between deterministic rule execution and adaptive learning, enhancing situational awareness in air traffic management.

#### 3.2.1.7 Knowledge graph for trajectory prediction and conflict detection and resolution

A knowledge graph for trajectory prediction and conflict detection/resolution (CD&R) in the AWARE project is constructed by integrating multiple data sources, structuring relationships between entities, and applying reasoning algorithms to infer potential conflicts and resolution strategies. The knowledge graph ingests standardized aviation data formats such as FIXM and AIXM to ensure semantic interoperability. However, as noted, these models primarily define the structure of operational data rather than providing the actual data itself. The necessary operational data for trajectory prediction and conflict identification must be obtained from dynamic sources such as ADS-B transmissions, 4D trajectory (4DT) predictions, flight plans, and airspace constraints. The ASA system knowledge graph is presented in flow chart form in Figure 10.

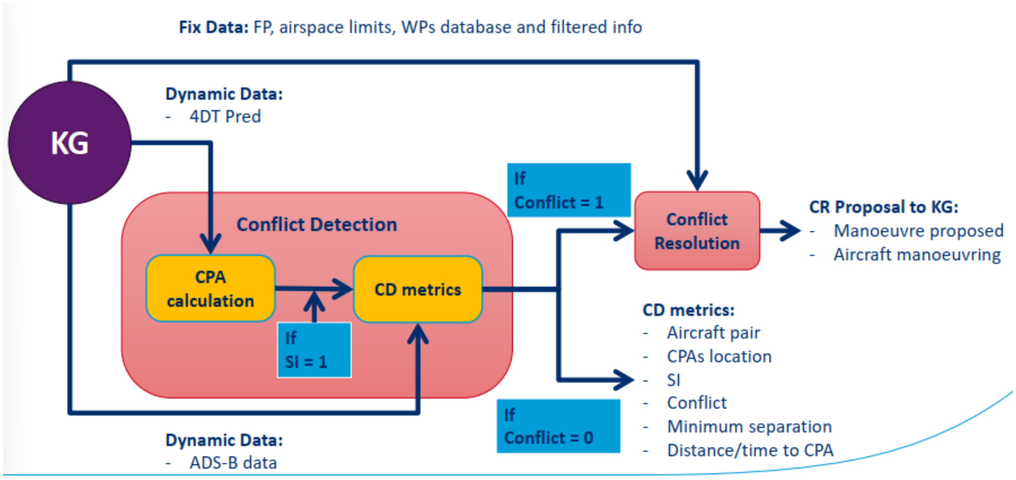


**Figure 10. ASA system knowledge graph flow chart**

The conflict detection process relies on 4DT predictions and ADS-B timestamps to evaluate potential separation infringements between aircraft pairs. The knowledge graph structures this information by defining key entities such as aircraft, airspace sectors, waypoints, and conflict conditions. The CD algorithm operates in a two-step method: first, it calculates the closest point of approach (CPA) between aircraft pairs based on time-correlated 4DT predictions. Second, it evaluates separation variables at the CPA to determine whether a situation of interest (SI) or a conflict exists. The knowledge graph supports this process by enabling rapid querying of aircraft states and their relationships, allowing for efficient detection of separation violations.

For conflict resolution, the knowledge graph provides structured reasoning capabilities by capturing expert knowledge and hierarchical resolution strategies. The CR algorithm considers various resolution options, including altitude adaptations, waypoint redirections, and heading adjustments. The knowledge graph facilitates decision-making by linking aircraft states with predefined resolution strategies, ensuring that solutions comply with operational constraints. Inputs to the CR function include outputs from the CD process, flight plans, airport and waypoint databases, and aircraft performance limitations. By structuring these elements within a unified framework, the knowledge graph enhances the ASA system's ability to provide ATCOs with effective resolution strategies.

To ensure accurate trajectory predictions and conflict identification, the operational data must be continuously updated. While FIXM and AIXM provide a standardized schema, real-time data sources such as ADS-B, surveillance radar feeds, and airline flight planning systems are essential for populating the knowledge graph. Additionally, historical flight data and meteorological information can be integrated to refine prediction accuracy. By leveraging these diverse data sources, the knowledge graph serves as a dynamic representation of the airspace environment, supporting advanced situational awareness and decision-making in air traffic management.

### 3.2.2 Stakeholders

In the AWARE project, stakeholders have been identified and involved throughout the development process. The project has engaged a diverse range of stakeholders, including the SESAR Joint Undertaking, the ATM research community, industry partners, etc. These stakeholders are consulted to ensure that the project's goals and outcomes align with the needs and expectations of the broader air traffic management community. Stakeholder engagement has been facilitated through workshops, presentations, and direct communication, ensuring their input is integrated into the project's results.

The feedback from these stakeholders is documented in the project’s deliverables, providing a clear record of their contributions to the development process. This approach ensures that the AWARE solution is shaped not only by the project's internal expertise but also by the valuable insights provided by external stakeholders. The strong interest demonstrated by the stakeholders was evident during their participation in the ConOps workshop, where they attended in significant numbers. This group represented a diverse array of air traffic experts, encompassing various backgrounds and areas of expertise within the field. Through targeted communication and dissemination activities, including newsletters, social media, and participation in key industry events, the project has gained continuous engagement and enthusiasm among its stakeholders, ensuring ongoing support and collaboration.

### 3.2.3 Key scenarios

The following scenarios in Table 3 provide detailed examples of how the AWARE solution will function within the operational and technical context of air traffic management. These scenarios are designed to illustrate the practical application of the Artificial Situational Awareness system, highlighting its capabilities in enhancing human-machine collaboration, improving safety, and increasing efficiency across different phases of air traffic control.



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Table 3. Key scenarios related to the AWARE solution

| Scenario | Scenario description | Stakeholder involvement | Stakeholder interaction |
|---|---|---|---|
| Scenario 1: Enhanced Situational Awareness in High-Traffic En-Route Airspace | In busy en-route airspace, the ASA system uses real-time data to construct a knowledge graph, identifying potential conflicts and providing the ATCO with timely suggestions. The system's human-machine interface ensures ATCOs receive relevant information without distraction. | – ATCOs interact directly with the ASA system, receiving support in real-time.<br>– Supervisor (SUP) is alerted when ATCO experiences degraded situational awareness<br>– ATSEP are notified about system's status and performance (including that of machine learning modules) | – ATCOs receive real-time suggestions from the ASA system, and if the system detects degraded situational awareness, it immediately alerts the SUP, prompting mutual communication to address any operational concerns.<br>– SUPs can escalate system performance concerns to ATSEP if alerted to potential issues from the ATCO, ensuring a coordinated response to maintain situational awareness and system reliability. |

| Scenario | Scenario description | Stakeholder involvement | Stakeholder interaction |
| --- | --- | --- | --- |
| Scenario 2: Supporting ATCOs in execution of their tasks and autonomous execution of tasks | During peak traffic, ASA system autonomously detects and predicts conflicts. It suggests resolutions to the ATCO, who can approve them or choose to delegate specific low-complexity tasks for autonomous execution. In such cases, the ATCO remains in-the-loop and is continuously informed of all actions performed by the system, ensuring full operational awareness and intervention capability if needed. | – ATCOs are central to the decision-making process, with the flexibility to adjust the automation level.<br>– ATM industry partners evaluate the integration of these automated tools with existing air traffic management systems.<br>– Decision-makers review the system's impact on overall air traffic efficiency and safety. | – ATCOs and industry experts participate in simulation exercises to assess the effectiveness of the conflict resolution tools.<br>– Feedback is documented and used to refine the system, ensuring it meets both operational and regulatory requirements. |

| Scenario | Scenario description | Stakeholder involvement | Stakeholder interaction |
|---|---|---|---|
| Scenario 3: Training and Integration of New ATCOs | New ATCOs train with the AWARE system, simulating complex scenarios to develop skills. The system's explainable AI provides clear reasoning behind actions, aiding learning. | – Training institutions integrate the AWARE solution into their curriculum.<br>– Experienced ATCOs provide mentorship, helping new ATCOs understand how to use the system effectively.<br>– Industry partners offer insights into improving the system's training modules based on real-world needs. | – Trainees, trainers, and industry experts collaborate in designing training modules, ensuring they meet both educational and operational standards.<br>– Feedback from trainees is collected to continually enhance the training experience and ensure smooth integration of the AWARE system into everyday ATC operations. |

Scenario 3, while incorporating training elements, is a real operational scenario focused on the onboarding and integration of newly qualified ATCOs into active roles. It illustrates how the AWARE system supports skill acquisition and safe system use during the early phases of controller deployment. It is distinct from Scenarios 1 and 2, which address system behaviour under live operational conditions with experienced ATCOs, but complements them by showing how AWARE functions when integrated into routine operational training pipelines and real-world air traffic control environments.

### 3.2.4 Potential limitations, weaknesses and constraints

The AWARE solution might face constraints that may impact the concept or the solution. Table 4 lists the requirements and barriers that could constrain the effectiveness of the AWARE solution.



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**Table 4. Requirements/barriers to the AWARE project**

| Requirement/Barrier | Project assumptions |
|---|---|
| Requirement: CPDLC | Autonomous direct-action support to ATCO depends on datalink. Many aircraft already use it routinely, and in the future the fraction of those will only rise. |
| Requirement: mature semantic technologies | Currently, the project uses semantic technologies that are still evolving. In the future, these will mature to a level which allows higher computational efficiency and more widespread support. |
| Barrier: Acceptance of human-machine teaming concepts | This is a potential barrier that challenges all new technologies – acceptance by users. We believe that our concept will be readily accepted by ATCOs because it empowers them. However, ANSPs might be slower to accept it due to costs involved with upgrading their controller working positions. SESAR can provide some relief to the ANSPs by driving the cost of development down in coordinated action with stakeholders. |
| Barrier: Push towards full automation | Parts of the research and industry community are advocating full automation of the ATC. If their ideas are translated to policy, it will result in human-machine collaboration being moved to the fringe of the research space. This project is a deliberate attempt at proving that collaboration, while difficult to implement, might provide benefits that full automation cannot. |

## 3.3 Expected performance outcome

For the AWARE project, the following KPA performance outcomes were used for development of the AWARE ConOps:

- Environment - Within AWARE, both aiding ATCOs and performing autonomous tasks are functions based on expert knowledge. By applying that knowledge to current and future traffic, a higher percentage of aircraft operations is optimised, leading to a potential reduction in the environmental effects of the aviation industry. On a more specific level, AWARE enables autonomous execution of tasks related to quality-of-service improvements (e.g. direct-to instructions) which ensures that the aircraft fly their optimal routes even in situations where due to high workload ATCO could not spare time to facilitate such requests. Therefore, a moderate reduction in actual average $CO_2$ emission per flight (ENV1, [5]) is expected.

- Capacity - By using adaptable automation and by always keeping the ATCO in the loop, it will become possible to decouple, to an extent, the ATCO's workload from the airspace occupancy count. With ASA-based AI Assistant Application supporting ATCOs in performing their tasks or performing additional tasks autonomously, the amount of traffic that the ATCO can handle increases. This also frees up ATCO's cognitive capacity to deal, if necessary, with mixed mode operations such as might be expected with integration of new entrant aircraft types. Therefore, once the Solution is implemented, a significant increase in en-route throughput, in challenging airspace, per unit time (CAP2, [5]) is expected.
- Operational efficiency - Lowering of the ATCOs' workload via assistive automation and increasing the human-machine team output through automatized tasks leads to improvements in punctuality and overall operational efficiency. While AWARE does not directly influence traffic predictions and forecasts, their inclusion expands the shared situational awareness and enable improved AI action suggestions. Direct routes could be given to aircraft even in high complexity situations which would shorten the horizontal distance travelled. Thus, a moderate decrease in operational inefficiency (reduction in horizontal en-route flight inefficiency) is expected.
- Safety - Safety improvements provided by ASA solution are two-fold. Primarily, the system provides an additional safety net by keeping ATCOs in the loop and developing strategies in the case of loss of situational awareness. With the application of lessons learned from the AISA project to the development of AI Assistant Application, the system is able, to an extent, to understand its own performance and act accordingly. Overall, the project's contributions to safety are expected to increase the safety levels. Even though there is no performance indicator related to activation of safety nets, we think that this performance indicator should be introduced and measured. Keeping the ATCO in the loop would prevent activation of safety nets (e.g. STCA) so a moderate reduction of those alerts is expected.
- Security - Integration of the ASA-based AI Assistant Application with the existing ATCO workstations ensures improvements to other expected outcomes without affecting the current security levels. However, in terms of cyber security, the Artificial Situational Awareness can be used to detect anomalies in the data streams (e.g., resulting from spoofed ADS-B data) in the same way operational staff (ATCOs) are now trained to detect those anomalies once displayed on the CWP. Therefore, there is a low potential for increased level of security.

## 3.4 Key assumptions

The key assumptions regarding the AWARE solution have been categorized into four distinct areas to provide clarity and structure: technological, social/political, legal, and scope. The technological assumptions address the technical capabilities and integration of data exchange models and machine learning. The social/political assumptions consider the impact on human roles and integration within air traffic management. The legal assumptions ensure compliance with automation regulations and safety standards. Lastly, the scope assumptions outline the intended operational phases and future adaptability of the system.

Technological assumptions:

- The AWARE solution assumes the full utilization of datalink and Controller-Pilot Data Link Communications (CPDLC) systems for seamless communication between air traffic controllers and pilots. By leveraging these digital communication tools, AWARE aims to enhance situational awareness and decision-making in complex air traffic management environments. Datalink and CPDLC enable the efficient and clear exchange of critical information, reducing reliance on traditional voice communication, which can be prone to errors and delays. Within the AWARE framework, these systems support the automation of routine tasks and the delivery of timely, relevant information to ATCOs, allowing them to focus on higher-level decision-making. The integration of CPDLC also helps ensure that the artificial situational awareness system can accurately assess ATCOs' intents and goals, providing tailored support without disrupting their workflow. By assuming a future where these technologies are fully implemented, AWARE positions itself to contribute to a safer, more efficient air traffic management system.
- The AWARE solution assumes that aviation data exchange models like AIXM and FIXM are integral to its data collection processes, ensuring seamless integration of new automation tools into the SESAR Digital European Sky framework. By utilizing AIXM for aeronautical information and FIXM for flight-related data, AWARE aligns with the standardized formats that underpin modern air traffic management systems. This alignment facilitates the smooth incorporation of AWARE's artificial situational awareness tools into the broader SESAR ecosystem, enhancing interoperability and data consistency across platforms. These data exchange models ensure that the information driving AWARE's automation and decision-support systems is both accurate and up to date, supporting real-time situational awareness and effective human-machine collaboration. Ultimately, this approach positions AWARE as a vital component of the Digital European Sky, contributing to a safer, more efficient, and cohesive air traffic management environment.
- The AWARE solution leverages explainable machine learning models to enhance its artificial situational awareness system, ensuring that the automation tools it develops are both powerful and transparent. By using models that provide clear, interpretable insights into their decision-making processes, AWARE ensures that air traffic controllers can understand and trust the system's recommendations and actions. This transparency is crucial in complex, safety-critical environments like air traffic management, where ATCOs must remain in control and informed. Explainable models also allow for better integration with existing systems and help address any potential biases, contributing to the overall reliability and effectiveness of the AWARE solution within the SESAR Digital European Sky framework.

Social/political assumptions:

- The AWARE solution is designed with a fundamental principle: keeping humans in the loop and ensuring that AI serves as a supportive tool rather than a replacement. By integrating AI-driven automation into air traffic management, AWARE enhances situational awareness without sidelining the critical role of air traffic controllers. The system is built to assist ATCOs by providing timely, relevant information and automating routine tasks, allowing them to focus on higher-level decision-making. This approach not only improves efficiency but also maintains human oversight, ensuring that ATCOs remain central to operations. By avoiding the replacement of humans with AI, AWARE aims to create a collaborative environment where AI augments human capabilities, leading to safer, more effective air traffic management while preserving the expertise and judgment that only human operators can provide.

Legal assumptions:

- The AWARE solution is designed to fully comply with all relevant automation regulations and legislation in aviation. By adhering to ICAO standards, EUROCONTROL & SESAR guidelines, and FAA regulations, AWARE ensures that its automation tools meet rigorous safety, reliability, and performance criteria. The system's development incorporates human factors and data security considerations, aligning with best practices and regulatory requirements. This commitment guarantees that AWARE's technology not only enhances air traffic management but also adheres to the highest industry standards for safety and regulatory compliance.

Scope assumptions:

- While the AWARE solution is currently focused on enhancing situational awareness and automation in the en-route phase of flight, its underlying principles and technologies are designed to be adaptable across all phases of flight. By leveraging data exchange models like AIXM and FIXM and utilizing explainable machine learning models, AWARE can extend its capabilities to other phases, such as take-off, approach, and landing. The flexibility of the system allows it to provide timely support and decision-making assistance to air traffic controllers regardless of the flight phase, ensuring consistent safety and efficiency throughout the entire flight process. This adaptability positions AWARE as a comprehensive tool for improving air traffic management across all stages of flight.

# 4 Proposed SESAR solutions

**Table 5. Proposed applications**

| Proposed solution title | Proposed solution definition | Proposed solution description | Maturity at project start | Maturity at project end |
|---|---|---|---|---|
| Artificial Situational Awareness System | Artificial Situational Awareness System enabling human-machine collaboration by being aware of the ATCO's intent and goals, traffic situation, and its own state | The AWARE project proposes an advanced solution to improve human-machine collaboration in air traffic control. The core of this solution is the Artificial Situational Awareness system, which uses aeronautical information exchange models to build a detailed traffic knowledge graph. It integrates a reasoning engine with rule-based knowledge and machine learning modules for tasks like trajectory prediction and conflict detection. This system enhances safety by automating routine tasks, improves interoperability through advanced data management, and increases sector capacity by streamlining operations and facilitating automation integration. | TRL1 | TRL2 |

# 5 Plan for next R&I phase

Building upon the outcomes of the exploratory research phase, the next phase of research and innovation within the AWARE project should focus on advancing the areas that were limited by the scope of the current phase. The next phase will likely move towards more application-oriented exploratory research and initial validation, especially targeting operational environments within air traffic control that require enhanced situational awareness solutions. As the AWARE solution is currently being developed specifically for the en-route phase of flight, its initial focus is on enhancing situational awareness and automation within this segment of air traffic management. However, the potential for the AWARE system to be adapted and expanded to other phases of flight is significant. Recognizing the current project's limited scope, we propose that the next R&I phase concentrate on extending the capabilities of AWARE to cover all phases of flight, including take-off, climb, approach, and landing.

A critical limitation of the current phase has been the scalability of the Artificial Situational Awareness system across different operational environments. The next phase should aim at expanding the testing and integration of ASA system in high-complexity, large traffic areas, such as high-density terminal airspace. This will also include refining the system's knowledge graph and reasoning engine to accommodate the unique requirements and dynamics of each flight phase. For instance, the take-off and landing phases are characterized by higher traffic density and more complex decision-making scenarios, necessitating enhanced real-time data processing and more sophisticated machine learning models. Similarly, the climb and descent phases, with their specific altitude and speed adjustments, will require tailored automation support. By developing the ASA system to function seamlessly across all flight phases, we aim to create a comprehensive tool that provides consistent, high-quality support to air traffic controllers throughout the entire flight journey.

Further research is necessary to explore the dynamics of human-AI collaboration in real-world air traffic management scenarios. Special attention should be given to the design of user interfaces and decision-support tools that can seamlessly integrate with ATCO workflows across all flight phases, as outlined in the SESAR 3 Common Taxonomy. This research should address how these systems can reduce cognitive load while maintaining ATCO situational awareness, thus enhancing safety and efficiency during peak traffic periods. While the current project has focused on proof-of-concept testing and early simulations for the en-route phase, the next R&I phase must prioritize real-time operational validation across all flight phases. This expansion will involve validating ASA solutions for take-off, climb, approach, and landing, ensuring seamless performance throughout the entire flight journey. Specifically, validation exercises in medium- and high-complexity environments must be performed to assess the impact of ASA solutions on key performance indicators such as safety, capacity, and cost-efficiency. Environmental benefits should also be evaluated, particularly in terms of optimised trajectory planning, reduced fuel consumption, and lower $CO_2$ emissions resulting from more efficient decision-making and automation support. Coordination with SESAR 3 JU initiatives will be critical to align these validation efforts with broader European ATM goals.

Based on the Common Assumptions framework from SESAR, future research should also perform comprehensive cost-benefit analyses, particularly for solutions showing promise in early-stage testing. This analysis will help determine the economic viability of deploying ASA technologies across different scales of ATM operations. Additionally, performance metrics such as workload reduction, airspace capacity improvement, and safety enhancements should be measured consistently across the next phase.

Several activities were deprioritized in the current phase due to limited project scope. In the next R&I phase, emphasis should be placed on broader stakeholder engagement to ensure that the diverse needs of airports, en-route centres, and military stakeholders are fully represented. Expanded geographic testing, particularly in varying European climates and air traffic complexities, will be necessary to ensure that the ASA system adapts well to different environmental conditions. Regulatory and standardization pathways, which were deferred in the initial exploratory phase, must also be more deeply explored to pave the way for formal SESAR solution deployment. By developing AWARE to function seamlessly across all flight phases, not only will safety and efficiency in air traffic management be improved, but the benefits of the AWARE solution will be fully realized in all aspects of flight operations. This comprehensive approach aligns with the broader goals of SESAR and the Digital European Sky, positioning AWARE as a pivotal component in the future of aviation.




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# 6 References

## 6.1 Applicable documents

This concept outline complies with the requirements set out in the following documents:

### Project and programme management

[1] [101167442] AWARE Grant Agreement, [25/06/2024]

[2] SESAR 3 JU Project Handbook – Programme Execution Framework, [11/04/2022], [1.00]

## 6.2 Reference documents

[3] MINIMA Consortium, D1.1 State of the Art report, SESAR JU, H2020-SESAR-2015-1, Dec 2016.

[4] SESAR Joint Undertaking, Strategic Research and Innovation Agenda (SRIA), Luxembourg: Publications Office of the European Union, 2020.

[5] SESAR Joint Undertaking, European ATM Master Plan, Luxembourg, Publications Office of the European Union, 2019.

[6] CRIDA/ENAIRE, AIRBUS, BOEING, DSNA, DEEPBLUE, DLR, ECTL, ENAV, INDRA-ALG, ONB4, TELEPAZIO, DES Performance Framework, SESAR Joint Undertaking library, 2023.

[7] STRESS Consortium, D7.2 Final project results report, SESAR JU, H2020-SESAR-2015-1, Aug 2018.

[8] AUTOPACE Consortium, D5.1 Final project results report, SESAR JU, H2020-SESAR-2015-1, Apr 2018.

# Appendix A Concept of Operations Workshop (24 September 2024)

The AWARE ConOps workshop was held online on the Microsoft Teams platform on the 24th of September 2024 at 13:00 CET. A total of 46 attendees participated, including AWARE consortium members, stakeholders, and external participants. The session was recorded and will be made available on the AWARE project's YouTube channel and website. During the workshop, attendees were engaged through 9 interactive polls, with results to be presented later in this appendix. Figure 11 shows some attendees that were present during the workshop.

The agenda was as follows:

**13:00 - 13:30**: Introduction of the AWARE project (presented by Tomislav Radišić [FTTS])

**13:30 - 13:45**: Introduction of the Polaris System (presented by Ján Cafík [TERN])

**13:45 - 14:15**: AWARE Concept of Operations (presented by Tomislav Radišić [FTTS])

**14:15 - 15:00**: Discussion and Q&A

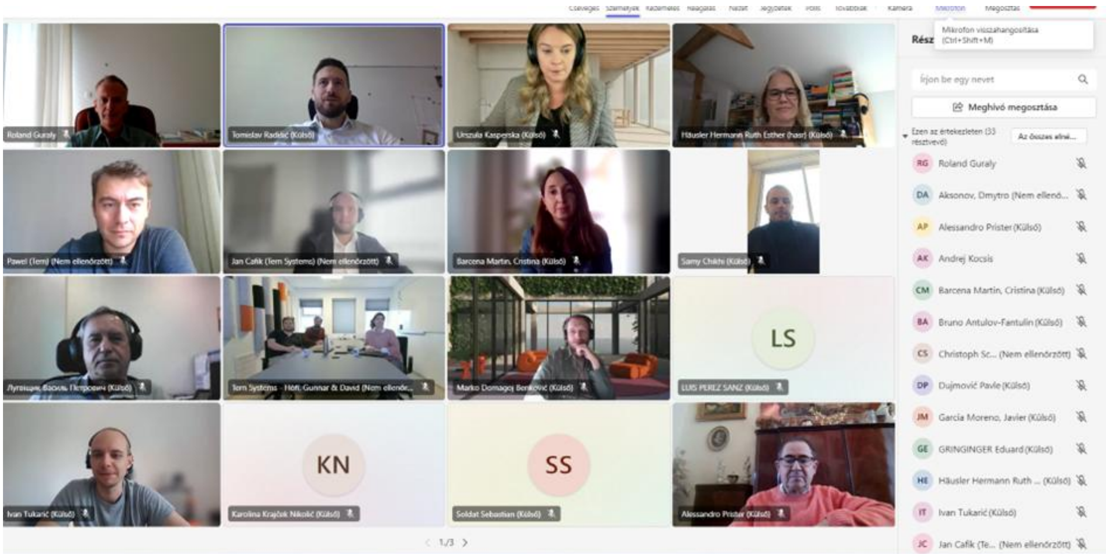


**Figure 11. ConOps workshop attendees**

Regarding the poll results, shown in Figure 12, a total of 46 attendees, representing academia, agencies, airports, airspace users, and industry professionals, shared their views. Key poll results revealed that 42% of attendees believed the main risk of implementing Level 2B automation in air traffic control is the potential over-reliance on AI, while 23% highlighted the risk of insufficient human oversight. Regarding AI decision-making and human collaboration, 48% agreed that AI would handle routine tasks, but humans would still make critical decisions.

In terms of the future of ATM by 2035, 44% envisioned AI supporting ATCOs in achieving their goals through cooperation, while 34% expected human-AI collaboration to achieve shared objectives. On whether the tools presented during the workshop would provide capacity benefits, 45% believed some benefits would be visible, though not as high as expected. Finally, regarding detecting degraded situational awareness (SA), 84% of attendees supported expanding the approach with more indicators like safety net activations, highlighting a preference for robust and diversified detection methods.

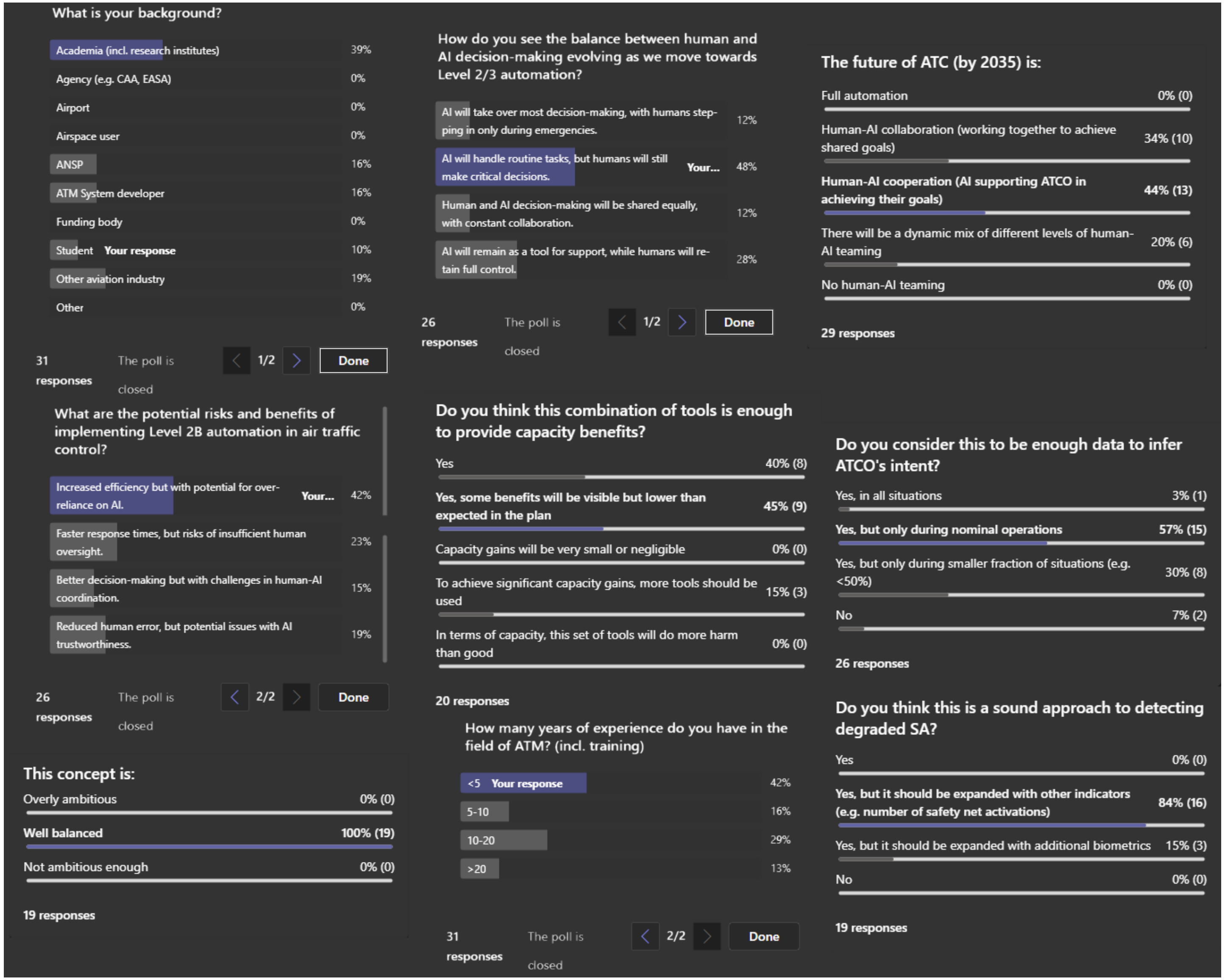


Figure 12. The nine polls and their results conducted during the ConOps workshop