# Concept of Operations for AI Situational Awareness

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| **Deliverable ID:** | **D2.1** |
| **Dissemination Level:** | **PU** |
| **Project Acronym:** | **AISA** |
| **Grant:** | **892618** |
| **Call:** | **H2020-SESAR-2019-2** |
| **Topic:** | **SESAR-ER4-01-2019** |
| **Consortium Coordinator:** | **FTTS** |
| **Edition date:** | **31 January 2021** |
| **Edition:** | **00.01.01** |
| **Template Edition:** | **02.00.02** |

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EUROCONTROL
SESAR JOINT UNDERTAKING

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## Document History

| Edition | Date | Status | Author | Justification |
|---|---|---|---|---|
| 00.00.01 | 23/07/2020 | Initial draft | Mia Bazina | New document |
| 00.00.02 | 24/08/2020 | Draft | Dorea Antolović | New sections |
| 00.00.03 | 31/08/2020 | Final draft | Tomislav Radišić | First final draft |
| 00.00.04 | 23/09/2020 | Comments integrated | Tomislav Radišić | Comments integrated to final draft |
| 00.01.00 | 30/09/2020 | First Issue | Tomislav Radišić | First issue |
| 00.01.01 | 31/01/2021 | Revised Issue | Tomislav Radišić | First revision of the document |

## Copyright Statement



# AISA

AI SITUATIONAL AWARENESS FOUNDATION FOR ADVANCING AUTOMATION

This deliverable is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 892618 under European Union's Horizon 2020 research and innovation programme.

## Abstract

This concept of operations is developed as a base for human-machine distributed situational awareness that will be used as support in en-route ATC monitoring tasks. It proposes the monitoring tasks which could be assigned to AI in this project. The concept of operations describes the expected changes between the current concept of operations, future concepts which do not consider human-machine distributed situational awareness, and the proposed concept which includes the AI into the team situational awareness. The proposal is to build a foundation for automation by developing an intelligent situationally-aware system. In order for AI to be as useful as human ATCO as much as team members, AI must see the same problem and be able to derive the same conclusions as if human brain works. The challenges of transparency and generalization are going to be solved by combining machine learning with reasoning engine (including domain-specific knowledge graphs) in a way that emphasizes their advantages. The proposed artificial situational awareness system will be the enabler of future advanced automation based on machine learning. This document will be useful to partners involved in the project as a basis for further research and reference in subsequent deliverables, especially in the development of the deliverable D2.2 Requirements for automation of monitoring tasks via AI SA.

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## Executive Summary

This Concept of Operations (ConOps) is a document describing the proposed AI Situational Awareness System (AI SAS). The set of requirements is not described here, but in the deliverable D2.2 Requirements for automation of monitoring tasks via AI SA.

This ConOps forms a basis for the AI Situational Awareness Foundation for Advancing Automation project. It is a Concept of Operations that describes digitalisation and automatization within the ATM environment. In order to implement some advanced automation concepts, the main requirement would be for the AI and human to be able to share a common situational awareness. One of the main objectives is, therefore, to explore the effect and benefits of common human-AI situational awareness during en-route ATC operations. This project is focused on building a foundation for automation by developing an intelligent situationally-aware system. Shared situational awareness experienced by both ATCO team members and AI is going to provide the automated system with sufficient knowledge in order for it to reach the same conclusions as ATCOs. The AI will be able to explain the reasoning behind its decision when confronted with the same problem as the ATCO.

The current downside of using AI in aviation is a lack of transparency. In other words, the system functions as a black box, with the user controlling the input and receiving an output from the machine that, even if it is satisfying and expected, cannot be explained. The machine lacks the possibility to explain and justify the processes that lead to generating the visible result. To avoid a “black box”, machine learning will be combined with the reasoning engine. Machine learning is going to be used for prediction, estimation and filtering at the level of individual probabilistic events, and the reasoning engine is going to represent knowledge and draw conclusions based on all the available data and explain the reasoning behind those conclusions. The AI situational awareness system (AI SAS) proposed in this project is going to be the enabler of the machine learning-based future advanced automation.

This ConOps is divided into four sections: Current Concept of Operations, Future Concept of Operations according to ATM Master Plan, AISA as an Enabler of the Future Concept of Operation, and Project-level Concept of Operations. The first section serves for the introduction. The second section is based on the current situation in en-route traffic. It describes the currently used technologies and rules, as well as the current tasks performed by ATCOs. It also gives insight about artificial intelligence and situational awareness, the two main concepts of this project. The third section describes changes in the future of air traffic according to the ATM Master Plan. It encompasses the SESAR vision, the performance view and all the operational changes relevant for this project and en-route traffic. The fourth and probably most important section talks about the AISA concept itself and what it brings to the table. It is focused on explaining how the AI will be implemented into the team SA, what tasks can it take over and what benefits it brings in the future. Fifth and final section goes into more detail about the project-level concept of operations, technologies used to develop the proof-of-concept system, and methodology for assessment of artificial situational awareness.

## Intended Audience

This document is intended for use by those employed within SESAR Joint Undertaking and by the experts from the ATM community, other professionals working on research and development, those employed in EUROCONTROL and the ANSPs who might take advantage of the proposed methods. This document should set the basis to describe the envisioned future ATM working environment where AI would act as an additional team member for ATCOs as well as to conduct further research at a later stage of the AISA project. In particular, this document will be useful to partners involved in the project as a basis for further research and reference in subsequent deliverables.

# 1 Introduction

This project aims to research the effects of human-machine distributed situational awareness for the purpose of automating monitoring tasks in en-route operations. The main research question to be answered is whether an AI system can be made aware of the situation, in a narrow ATC-specific scope, by using current state-of-the-art technology, and can that awareness provide transparency and generalization required of such systems. We hypothesize that machines can be aware of the situation, including its own state, in a domain-specific way, and it can take part in the team situational awareness and that such a system can be used to automate monitoring tasks in a transparent manner. The goal is to develop a Concept of Operations for en-route ATC with AI taking part in team situational awareness. We aim to define which monitoring tasks could be assigned to AI and what kind of system must run in the background to accomplish those tasks. During this project, it will be analysed which monitoring tasks exist, which of them can be automated in different scenarios (medium/high automation), and most importantly what are requirements for their automation in terms of needed data, changes in operations, changes in user interface, and the possible effect on human operators. This ConOps will describe the expected changes between the current concept of operations, future concepts which do not consider human-machine distributed SA and the proposed concept which includes the AI into the team SA [1].

## 1.1 Definitions

**AI Situational Awareness System (AI SAS)** will be the AI part of the ATM environment in the envisaged future (2035-2040) implemented by ATM system providers. In some cases, the system is referred to as "AI-based support system".

**ATM Environment** is the overall set of systems, processes, functions and infrastructure where air traffic control takes place. The current environment describes the status during the preparation of this document (e.g. 2020) whereas the future environment forecasts the likely situation in 2035-2040.

**Artificial Intelligence** is the ability of a digital computer or computer-controlled robot to perform tasks commonly associated with intelligent beings. The term is frequently applied to the project of developing systems endowed with the intellectual processes characteristic of humans, such as the ability to reason, discover meaning, generalize, or learn from past experience.

**Automation** is the creation of a technology that will execute a certain task, or a certain set of tasks automatically.

**Conflict** is an event in which the time interval/distance/other parameters between two or multiple aircraft violate the normative separation [2].

**Situational Awareness (SA)** is the perception of environmental elements and events with respect to time or space, the comprehension of their meaning, and the projection of their future status.

**Shared or Team Situational Awareness (TSA)** means two or more people have a commonly understood mental image of what is happening and/or what is going to happen in the near future.

The complete list of acronyms and definitions of the terms mentioned in this paper can be found at the end of the document in the Appendix A – Glossary.

## 1.2 The vision of the AISA project

AISA project vision is for the AI to be able to serve as platform. Other automated tools would be able get important data from the platform, thus the AI will have sufficient situational awareness to be able to automatise certain ATCO monitoring tasks further discussed in this document.

AISA will consist of both human and machine (AI) actors that will be working together as a team and share a team situational awareness. By doing so, the AI will be capable of taking over some monitoring tasks, warn the ATCO if they were to lose SA and need to respond to a situation at hand, as well as support the ATCO's decision-making process by giving suggestions.

For AISA to be a part of the air traffic future, the assumption is that most new advanced technologies described in the ATM Master Plan will be available which is a necessary prerequisite considering the high automation of AISA.

Unlike most AIs of today, the goal of the AISA project is to avoid a so-called "black box" issue by combining machine learning with the reasoning engine. Regarding the "black box" issue, the user usually controls the input and receives an output from the machine that cannot be explained. The machine lacks the possibility to explain and justify the processes that lead to generating the visible result. In AISA the situationally-aware system will not be simply obeying certain laws and rules and react accordingly, but will also be capable of explaining why it made a certain decision.

## 1.3 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 nominal en-route operations and the expected future operational scenario settings as the basis for developing the AISA concept. The current version sets the way for the forthcoming actions of the AISA project. Nevertheless, revision of the AI-related concept of operations will be necessary as knowledge on artificial intelligence increases.

## 1.4 Structure and methodology

This document describes the expected changes between the current concept of operations in en-route air traffic control, future concepts which do not consider human-machine distributed SA, and the proposed concept which includes the AI into team SA. The working approach includes interviews with air traffic controllers (ConOps workshop) and the analysis of current and future tasks in ATC to single out the areas where AISA could bring the most benefit. We believe that by combining reasoning engine with ML, it will be possible for AI to be 'aware' of the situation like a human is. In other words, AI will have the capability to assess complex interactions between objects, draw conclusions, explain the reasoning behind those conclusions, and predict future system states.

The second section, Current Concept of Operations, describes the current capabilities of en-route air traffic control. It covers the used technologies and rules and provides a comprehensive list of current tasks as performed by ATCOs. It introduces artificial intelligence and situational awareness as two basic enablers of the AISA concept.

The third section, Future Concept of Operations according to ATM Master Plan, describes the expected changes in the future air traffic operations as described in the Master Plan. The tasks listed in the first section are observed again, including the effects of the expected technological advancements.

The fourth section explains the basic concept of the AISA project and its effect on ATC. It focuses on explaining the way AI will be implemented into the team SA and which tasks it can take over from the ATCOs, as well as the benefits that will bring. This section is directly linked with the general requirements in the D2.2. Requirements for automation of monitoring tasks via AI SA.

The fifth section goes into more details regarding the development of the proof-of-concept knowledge-based system intended to achieve the artificial situational awareness during the project itself. Technical details, technologies used, and assessment methods are presented. This section is directly linked with the project-level requirements in the D2.2. Requirements for automation of monitoring tasks via AI SA.

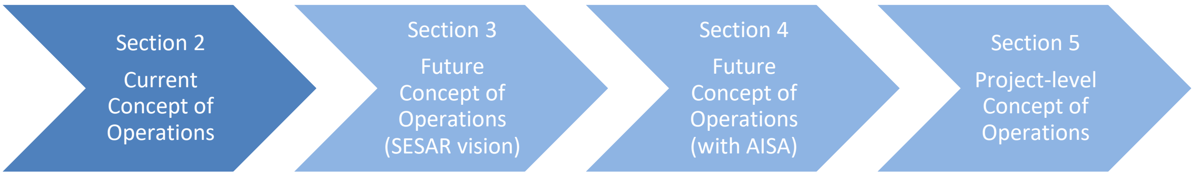
Appendices at the end of this document contain a glossary of all terms and acronyms, a detailed description of en-route air traffic control, and artificial intelligence. The last appendix, Appendix D, contains data extracted from the answers of polls held during the first AISA webinar.

## 1.5 Relations to other documents

A full list of references used can be found at the end of the document. The document is linked to several SESAR and ATM documents, here only the most relevant ones are listed:

- SESARJU, “AISA Grant Agreement No 892618.” 2020. [1]
- SESARJU, “European ATM Master Plan 2020.” 2020., [3]
- ICAO, Procedures for air navigation and air traffic management pans-atm doc 4444. ICAO, 2016. [4]
- AISA D2.2: Requirements for automation of monitoring tasks via AI SA

# 2 Current Concept of Operations




## 2.1 Current Operations

En-Route Control provides separation between aircraft that are operating in a controlled or in advisory airspace. They do this in comformity with airspace classification as well as aircraft flight rules. Air Traffic Control (ATC) issues clearances to aircraft that are based on the requirements necessary for providing ATC services within the airspace. Limits of the area within which Air Traffic Services (ATS) are provided are determined by equipment coverage, even though it may be further limited. En-Route Control sometimes provides ATS in airspace that is usually the province of another control unit and can do so on a permanent or limited basis.

An ACC consists of several sectors and they all cooperate closely. The method of operation is different at each centre but it is always based on the same principles:

- controllers are responsible for the efficient performance only of those tasks that are specifically assigned in their task description;
- controllers must monitor other members of their sector team and their actions, but only to the extent that prime duties permit;
- all sectors must have a display that allows them to detect a conflict, and that display should reflect all issued clearance instructions and received communications;
- purposes of co-ordination between sectors require some criteria which enable the co-ordinator (when such thing is authorized by the CAA) to use information obtained by surveillance for the transfer of traffic between sectors without referencing the controller [5].

### 2.1.1 Rules and separation methods

Different separation standards allow aircraft to safely navigate in controlled airspace. These standards serve as an insurance of safe separation from the ground, other aircraft and various protected areas of airspace. These standards' aim is the reduction of exposure to Wake Vortex Turbulence, even though there are many situations regarding wake vortex that lead to separations much greater than the minimum separation. National separation standards are based on the ICAO Doc 4444 and if they differ from these standards, then those deviations are published in national Aeronautical Information Publications (AIPs). There are different methods Air Traffic Control Officers (ATCOs) use to achieve separation, some more complex than others, and they depend on the aircraft's phase of flight and its relative trajectories. The separation methods listed below are some of the simpler methods used in en-route air traffic control.

When talking about air traffic, we can separate flights into those flying by IFR rules and those flying by VFR rules. ATCOs have a duty of separating them according to the class of airspace in which aircraft are flying. Different types of separation can be used having in mind the situation at hand. Vertical separation is achieved when aircraft in close proximity operate at different levels expressed in terms of altitude or flight level (FL). This type of separation is normally used when aircraft are on crossing paths or have to fly a certain portion of their path in the same direction, yet they are less than 5 NM apart horizontally. Minimum vertical separation, according to ICAO, is 2000 ft (600 m) for IFR flights that are above FL290 ft and up to FL410. In some airspaces, however, Reduced Vertical Separation Minimum (RVSM) is implemented, reducing the vertical separation minima between FL290 and FL410 from 2000 ft to 1000 ft. When the ATCO is not sure the aircraft will manage to climb/descend in time, they may issue a rate of climb/descent as means to achieve separation at a specific point or time.

Lateral separation can be achieved with different methods: ATCOs can request pilots to report their positions when they are overflying different geographic locations, as well as require them to fly on certain tracks that are separated by a minimum angle. Longitudinal separation refers to the spacing between succeeding aircraft that is never less than a specified minimum. For aircraft that are on the same or diverging tracks, this separation can be achieved by position reports from aircraft and the time comparison of their reports or by speed control.

The speed of the succeeding aircraft should not exceed the speed of the leading aircraft, however, it can be the same if there is already enough distance between them. Reduced separation can also be applied if the leading aircraft maintains a higher speed than the aircraft following it. This is called a Mach Number Technique and is described in ICAO Doc 4444 [4].

Separation minima that is based on ATS surveillance systems in use is 5 NM (unless the relevant ATS authority states otherwise). This minimum can be reduced even further by the appropriate ATS authority but it can never be below 3 NM when surveillance capabilities permit this, or 2.5 NM between succeeding aircraft that are on the same final approach and within 10 NM of the runway threshold. Separation minima can also be higher than 5 NM horizontally if necessary in certain parts of the airspace and/or at certain times.

ICAO also categorises aircraft according to their Maximum TakeOff Mass (MTOM), then minimum separation times or distances apply to aircraft in sequence. Aircraft that are following a higher MTOM aircraft get more spacing than those aircraft following the same or lower MTOM category [4]. A newer classification called RECAT also exists which is not solely based on the aircraft's weight on which ICAO wake vortex separation rules are based. During emergency situations, emergency separation is used. Since sometimes ensuring sufficient horizontal separation during an emergency is not possible, it is allowed to use half the applicable vertical separation minimum during such situations. Another way of separation can be acquired through coordination with other ATCOs since ATC units forward each other the necessary information about flight plans and control. There is an agreement between ATS authorities where they have to assist in aircraft separation when it is so required.

### 2.1.2 System for monitoring the air traffic

To monitor aircraft and their height-keeping performance, specialised systems are used that collect necessary data using estimations of relevant performance parameters, as well as comparison of these parameters in relation to RVSM requirements. This is done on both an individual-aircraft level and a system-wide basis. Main monitoring tools in the air traffic industry are the primary and secondary radar. A primary surveillance radar (PSR) works on the principle of a radar pulse which is transmitted from the ground-based antenna and then listens for the answer in the shape of returned energy reflected from an aircraft. By doing so, a measure of the range is obtained through a simple calculation of the time delay between the transmission of the pulse and its reflected return. PSR provided continuous surveillance of air traffic, independent from the radio position reports, and it also reduced the procedural separation standards since it offered increased precision. Its flaw, however, is the inability to positively identify each aircraft. The secondary surveillance radar (SSR) was made having in mind the PSR faults. That is why the SSR relies on a transponder, a radio receiver, and a transmitter that operates on the radar frequency. SSR can detect and identify aircraft as well as provide the Flight Level (its altitude based on pressure) of an aircraft which brought in quite a few advantages to ATC surveillance [6]. For example, ATCO is able to see the aircraft code and the aircraft height on their display thanks to the SSR. Lately, because the historical SSR systems have reached the limit of their operational capability, Mode S has been deployed. Mode S data updates rapidly, is very accurate and provides pilots and ATCOs with common air situational awareness, and it works in a combination with the Automatic Dependent Surveillance (ADS). The availability of satellite technology brought with it the possibility of other types of ATC surveillance equipment such as the mentioned ADS. ADS is a datalink system used to transmit data from the aircraft. This data includes aircraft's position, altitude, as well as the intended flight path to the ground system. The original ADS system is also known as ADS-C (or ADS-Contract) because the aircraft reports are generated in conformance with a so-called contract that is set up with the ground system. These reports are a replacement for pilot's verbal reports and allow procedural separation.

Another important information source for ATCOs is the Flight Progress Strip (FPS), commonly referred to as just a flight strip. It can be either an electronic or a paper strip and it contains planned and current flight plan data for that specific flight. All the data about the flight is shown in a tabular form that makes it easy to find relevant data quickly. Each flight strip field holds a certain piece of information about the flight (e.g. aircraft identification, type of aircraft, SSR code, departure airport, destination airport, cleared FL, etc.). The ATCO can also write down, or type in, important information about the flight, such as clearances and estimates.

### 2.1.3 Means of support

In recent years, the automated systems which provide decision support, or automated features which alert or send warning messages to ATCOs, have exceptionally progressed. Below are several examples of such state-of-the-art tools that many of the European ANSPs employ today.

#### 2.1.3.1 Separation tools

ATCO are supported in their work today by the use of automated separation tools listed below.

<u>QDM - Range and Bearing tool</u>

- allows ATCOs to measure range and bearing between any aircraft
- displays how far apart the aircraft are in terms of minutes

- the range and bearing measurements can be done between two fixed points or between a point and an aircraft

SEP -Separation display tool

- displays the minimum separation distance of aircraft and how long will it take for them to reach that distance
- only available for aircraft with converging tracks
- will produce an alert if necessary

Probe tool

- allows ATCOs to test if a planned clearance will cause a conflict without having to make any changes to the flight
- when used before a clearance, it shows a temporary trajectory and potential conflicts should the controller decide to issue the clearance

MTCD -Medium-Term Conflict Detection (See Figure 1)

- warns the controller about potential conflicts between flights in their area of responsibility up to 20 minutes before they occur
- trajectory prediction, conflict detection, trajectory update, and edition
- notifies the controller of probable loss of separation between two aircraft, of aircraft penetrating segregated or restricted airspace and of aircraft-to-aircraft encounters in which certain aircraft is blocking airspace that could be used by another aircraft [7].

TCT -Tactical Controller Tool

- short term conflict detection tool (it warns the ATCO 5-8 minutes ahead) and a clearance verification tool
- one of the most helpful tools for an executive ATCO as it is used both in en-route and TMA and warns the ATCO of potential conflicts in their sector
- critical missed manoeuvre indicator shows where the loss of separation will occur if an aircraft does not make a planned manoeuvre [8].

DAP -Downlinked Parameters

- feeds information from the aircraft flight management system and enhances basic functions
- provides enhanced trajectory prediction, better quality of the Flight Path Monitoring (FPM) tool, improved situational awareness (SA), improved guidance, and reduced voice communication requirements
- requires an aircraft to be equipped with relevant technology and the Air Traffic Management (ATM) system on the ground that supports the exchange of DAP information [9].

CARD - Conflict and Risk Display

- ATCOs can highlight the detected conflict or choose to remove the highlight as they please depending on the subjective severity of the conflict
- warns the ATCO by changing the colour of the conflict to indicate an increased or decreased severity of the situation

Flight leg and flight leg embellishment

- aid ATCOs in predicting future traffic situations and potential conflicts by allowing them to visualize the aircraft route
- flight leg only shows the aircraft route
- flight leg embellishment also shows potential conflicts with other aircraft and their routes by colour coding

Heading vector

- assignment of headings and/or direct routing

Range rings
- concentric circles around a specified point),

Scale marker
- graduation line

Geographical reference
- geographical reference for a selected point on the radar image

Level band highlight
- filtering the flight levels

SAP Segregated Area Probe
- lists warnings/conflicts

Vertical Aid Window
- predicted vertical profiles of aircraft flying through a sector

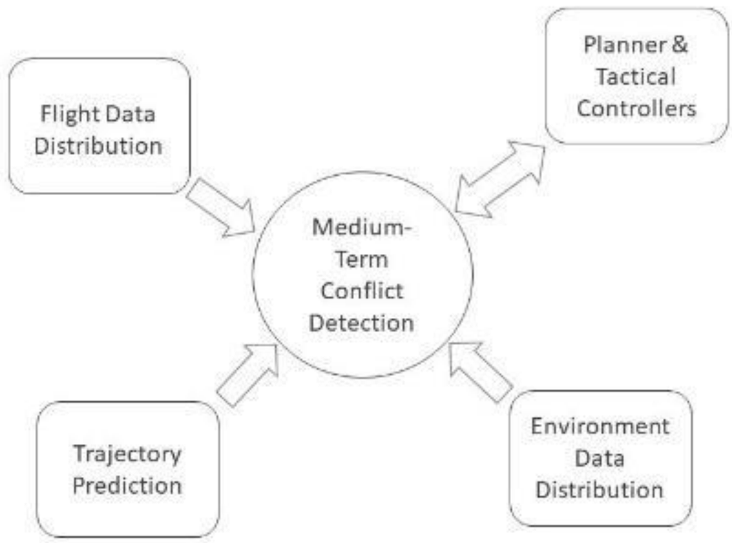



**Figure 1 MTCD context (Adapted from [7])**

### 2.1.3.2 Warning systems

Safety nets are used to warn air traffic controllers that might have lost situational awareness. They help in the prevention of impending or actual hazardous situations from evolving into major incidents or accidents. They can be either airborne or ground-based, and ground-based ones are the ones used by ATCOs. Ground-based safety nets are a crucial part of the ATM system that primarily use ATS surveillance data in order to give warning times that are up to two minutes. Once they receive an alert, ATCOs should react immediately and assess the situation in order to take appropriate action.

The following safety nets are commonly used in ATM automation systems:

- Short Term Conflict Alert (STCA) - assists the ATCO in a way that it prevents collision between aircraft by trigerring an alert in a timely manner, that warns the ATCO about a potential or actual infringement of the separation minima.
- Area Proximity Warning (APW) - warns the ATCO about unauthorised penetration of airspace by trigerring an alert on time to divert ATCO's attention to the potential or actual infringement of required spacing.
- Minimum Safe Altitude Warning (MSAW) - warns the ATCO about an increased risk of Controlled Flight Into Terrain (CFIT) by trigerring an alert in a timely manner about the terrain proximity of the aircraft, or proximity to other obstacles.
- Approach Path Monitor (APM) - warns the ATCO about an increased risk of CFIT by trigerring an alert in a timely manner about the terrain proximity of the aircraft, or proximity to other obstacles during the final approach [10].

### 2.1.4 Voice communication

Communication between ATCOs and pilots is an important process crucial for the safety and efficiency of air traffic control. Pilots report to ATCOs and receive instructions in an equally clear and distinct way. Voice communications between a pilot and the ATCO are usually accomplished using radiotelephony, broadcasting, as well as receiving on UHF (Ultra high frequency), VHF (Very high frequency), and HF (High frequency). VHF is vital for arrivals and departures, while HF usually serves for long-range communication and weather forecasts. UHF stations are mostly used in communications with military aircraft that are flying as operational air traffic (OAT). There is also use of a Satellite Communication (SATCOM) datalink but it is used only for a small number of en-route ATM communications which contrasts the extensive use of VHF and HF.

CPDLC (Controller Pilot Data Link Communications) is a two-way data-link system which was made as a resort for voice communications. ATCOs can use it to transmit non-urgent messages to an aircraft and those messages are then shown on a flight deck visual display. CPDLC is a great alternative to traditional air-ground data communication as it enables the communication messages exchange (clearance, information, request, etc.) corresponding to standard radiotelephony. Controllers can issue ATC assignments, transfer aircraft to different radio frequencies, and request various information. Pilots can easily respond to messages, request and/or receive clearances and information, as well as report various information. A „free text“ is also a possibility as it allows for the exchange of information that does not conform to predefined formats [11]. However, such communication via free text is discouraged as it can lead to misinterpretation. There is also a lack of possibilities as it is not yet possible to issue restrictions along with the clearances (e.g., rate of climb or rate of descent) and insufficient implementation of CPDLC in aircraft.

For a more detailed description of en-route air traffic and what it encompasses, see Appendix 2.

## 2.2 Operational modes

The single most important task an ATCOs has is to provide a safe, expeditious, and orderly flow of traffic. From the beginning of the shift, their tasks are sector supervision, relieving the position, control of sector traffic and in the end the handover of position. After that, all the other tasks regarding control of sector traffic follow and branch out to subtasks. This document will only provide insight regarding the first few levels of tasks, as AISA will not delve as deep. Tables below offer a short description of the most important tasks an ATCO performs during their daily duties.

| Procedural tasks | Description | Information Source | Tools used |
|---|---|---|---|
| Detect planned flight | Initial detection of the aircraft and its plan, ATCO gains knowledge of the aircraft location and planned intentions | Radar display, Flight Progress Strip (FPS) or trajectory route display | Colour-coding tools that filter new entries by changing the aircraft colour |
| Plan aircraft through the sector | Check the aircraft route for potential problems/conflicts and figure out solutions | Radar display, FPS/trajectory route display | Various probing tools, flight leg and flight leg embellishment tool |
| Assume, identify and confirm aircraft | Receive pilot's incoming report and reply with positive identification and initial clearance if required | VHF voice communication and/or datalink | Colour-coding tools that help ATCOs mark the assumed aircraft |
| Execute aircraft's plan | Check the aircraft and its plan periodically, ask the pilot to report if necessary and give appropriate instructions; Establish and maintain necessary separation and climb/descend/vector aircraft according to procedures | VHF voice communication, datalink, radar display, FPS/trajectory route display and use of ATCO memory | Different probing and planning tools, use of conflict detection tools if needed |
| Transfer aircraft | ATCO checks if the aircraft is clean and meets its planned exit, issues a change of frequency, verifies readback and transfers the aircraft to the next sector at its agreed exit conditions. | VHF voice communication, datalink and FPS/trajectory route display | Electronic coordination tool is used for handover if necessary, as well as colour-coding to indicate the aircraft is no longer under ATCOs supervision |

**Table 1 Procedural tasks (Adapted from [12])**

| Continuous tasks | Description | Information source | Tools used |
|---|---|---|---|
| Conflict management | Identification of the conflict; Confirm suspicion of a conflict and gather additional details. The ATCO can contact the aircraft directly to request aircraft state information. ATCO uses their solution library or comes up with novel solutions to solve the | ATCO's memory and/or experience, radar display, FPS/trajectory route display, E-FS, VHF voice communication | CDT (Long-term, Mid-term, Short-term) and/or other scanning/probing tools |

| | | | |
|---|---|---|---|
| | conflict. Update the aircraft plan with the conflict solution. | | |
| Conformance management | Identify the non-conformance by understanding the real-time status of the aircraft. Check if non-conformance is causing a conflict. Ask for the reason of non-conformance and choose if it can be allowed or correct it by routing or restating the previous instruction. | FPS/trajectory route display, radar display, E-FS, ATCO memory, VHF voice communication | Cleared flight Adherence tool (CLAM), Route Adherence tool (RAM) |
| Maximise quality of service | Look for QoS improvements from a/c position, from transit to exit. The best practice may already be a part of standard procedures The ATCO may ask for aircraft report to identify the best solution. The result of the QoS improvement is an update to the a/c plan which may require co-ordination. | Radar display, FPS/trajectory route display, QoS improvements library, R/T, telephone | - |
| Assess if exit conditions are met | The ATCO checks if the previously planned exit point and level will be reached. This may not be the case due to a conflict or the aircraft physically not being able to reach the exit conditions. In both cases, appropriate coordination or radar handover requests are assessed and planned. | Radar display, FPS/trajectory route display, information database | Probing tools |
| Workload monitoring | Knowledge of current and future workload as a result of incoming traffic and plans made upon it. Self-analysis of workload by controllers. | Controller workload self-assessment, current and future traffic data | - |

**Table 2 Continuous tasks (Adapted from [12])**

| Reactive tasks | Description | Information source | Tools used |
|---|---|---|---|
| React to unsolved entry problems | The PLC can't solve an entry problem, so they alert the EXE before their normal detection of the flight. The result is earlier | Radar display, reported information | - |

| | | | |
|---|---|---|---|
| | conflict detection and a solution that may require radar handover | | |
| Respond to safety nets alerts | STCA and MSAW alert the controller of an imminent conflict. The controller responds by solving the conflicts as if it has been detected by them. | STCA, MSAW, other safety nets | - |
| Respond to received co-ordinations | PLC responds to co-ordination from adjacent sectors. If an exit condition is changed, they notify the EXE. | Verbal, telephone, written | - |
| Respond to received radar handover proposals | Radar handover requires ATCO's immediate response as they have to assess the request, verify if the proposal is problem-free then decide whether to agree or disagree on the conditions; If an exit condition is changed, the ATCO updates the plan and issues the instructions | Telephone, FPS/trajectory route display | Various probing and conflict detection tools |
| Process special aircraft requests | ATCO receives a request that requires immediate response to which they assess it and decide to grant it, acknowledge it, deny it or make and alternative proposal | VHF voice communication, datalink, FPS/trajectory route display | Probing and, if needed, conflict detection tools |
| Respond to aircraft reports and distress signals | Responding to expected and unexpected (distress signals) reports from the aircraft | VHF voice communication, datalink, radar display | - |
| Respond to Estimated Time Over (ETO) revision | The response when an ETO change is received from the upstream sector; The aircraft is usually some distance from the sector in question when a revision is received | Telephone, FPS/trajectory route display | - |

**Table 3 Reactive tasks (Adapted from [12])**

As opposed to procedural tasks, continuous and reactive tasks may result in changes to the aircraft plan. These high-level tasks and its subtasks are found in Today’s Operations Task Analysis - Human Factor Assessment [12]. The tables above were modified to showcase the tools used for each task.

## 2.3 Situational Awareness in ATC

An air traffic controller's main responsibility is to maintain adequate separation between aircraft, and in order to perform their tasks, a certain level of SA must be maintained as well. If the level of SA drops, it can lead to loss of separation which is why staying vigilant is of utmost importance in ATC. Regarding the controller's job, SA means creating and maintaining a mental image of the traffic situation at hand, and keeping in mind that there is always a potential for further development of the current scenario [13].

### 2.3.1 Team situational awareness

When it comes to shared situational awareness, or team awareness, it can be said that the level of situational awareness a team can achieve is an overlap of each member's individual level of situational awareness. Team members anticipate and predict each other's needs and reactions to adapt to the situation and task demands thus coordinating activities in an effective matter. Without even realizing, teams achieve shared SA by combining the knowledge of facts, rules and different relationships. This also includes other background knowledge such as the knowledge of the system used, goals of designated tasks, system components and the relation between them, equipment used, roles and positions occupied, as well as knowing the team members themselves. It somewhat relates to a procedure, as in storage of relevant information that is necessary to accomplish certain tasks and the order in which they have to be resolved [14]. It is hard to pinpoint the context of situational awareness considering its rapid and continuous evolving. The positive thing is the improved and growing number of aids that help with enhancing one's situational awareness.

### 2.3.2 Situational awareness and automation

During the previous years, there weren't many tools that helped controllers maintain SA, and they mostly relied on their flight strips to maintain and/or regain situational awareness. Today, however, the automation has increased exponentially which doesn't necessarily mean better SA. On the contrary, because of the amount of automation and the abundance of information, it is just as easy to lose SA as it was back when not much information was available to the controller. Since situational awareness closely ties with short-term memory, it is easier to understand how the drastic increase of visual information presented to the controller during his shift can lead to a decrease of SA. Higher automation also poses a threat for a false sense of security controllers may feel considering the amount of help they are getting which leads to the out-of-the-loop effect where it is difficult for them to regain the SA after relying on the automation too much.

There has been some previous research regarding situational awareness in ATC. One of the basic models of SA was developed by Mica R. Endsley in their paper Toward a Theory of Situation Awareness in Dynamic Systems [15] back in 1995. In this model (Figure 2) the basis of someone's SA is the perception of the environment's relevant elements that are coming from system displays or by directly using senses.

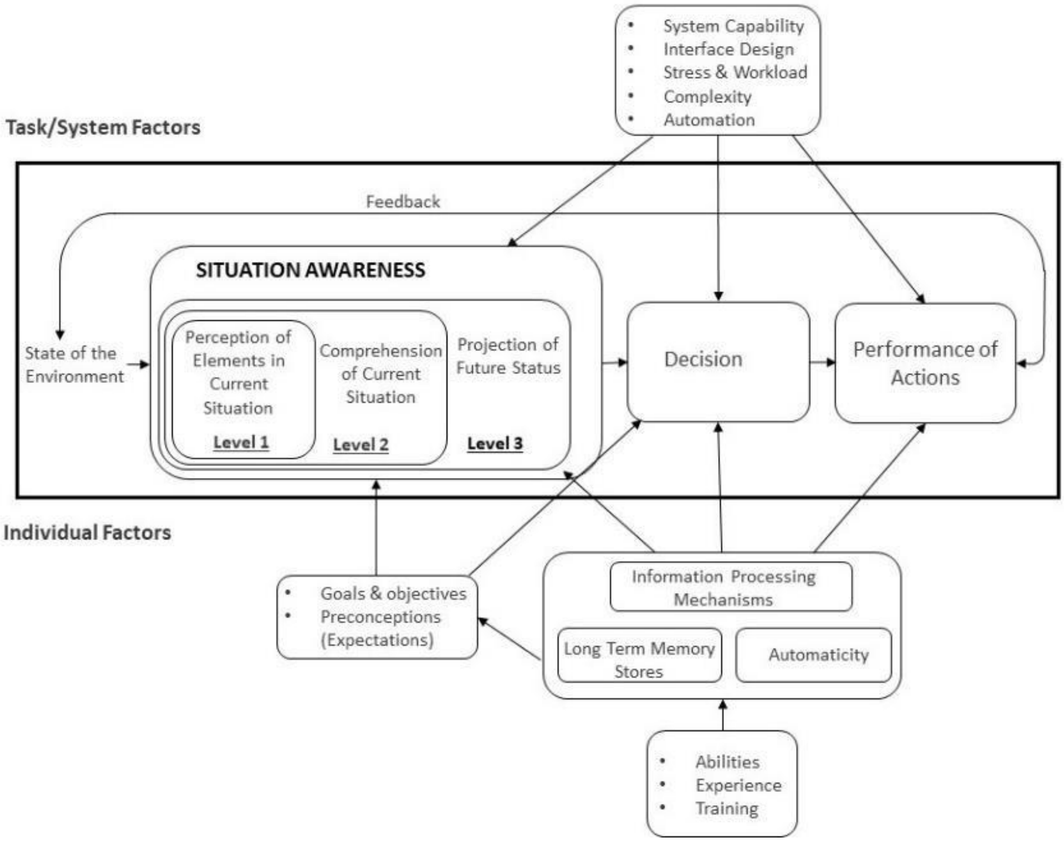



**Figure 2 Model of situation awareness in dynamic decision making (Adapted from [15])**

Some tools used to measure SA should also be mentioned. SART (Situation Awareness Rating Technique) is a tool that allows its users to rate a system design using scales, thus providing them with the degree to which the perception is experienced. It is unfortunately highly subjective and can be easily influenced by a controller's perceived performance, but it seems to be resilient to display manipulation. SAGAT (Situation Awareness Global Assessment Technique) assesses SA across multiple elements that are based on the controller's SA requirements. It is conducted using the freezing technique at random times during which the subject is questioned about the perception of the current situation. One of the flaws is the grading of responses that are only scored as correct or incorrect with just a few queries having a tolerance around the actual value. SPAM (Situation Present Assessment Method) is another query technique with queries similar to SAGAT ones, however, it does not use the freezing method and the controller is asked questions via their landline. Unlike the SAGAT, the data that is analysed is not the percentage of correct answers, but instead the delay (time passed) between the asked question and the given answer. The probe technique is also used to question the controller about the current state of their environment. It can be performed either offline when the computer simulation is paused, or online when the simulation is still running.

One of SESAR researches involving SA is the Enhanced ground controller situation awareness in all weather conditions project that is currently available for industrialization and/or deployment. It was based on the development of safety nets that will help controllers during their everyday work. Several prototypes of safety nets for controllers were validated since they increased SA in certain conditions and enhanced safety by generating real alerts. Another SA-related project is AIRBEAM (AIRBorne information for Emergency Situation Awareness and Monitoring). Its concept was based on developing a situation awareness system that will manage over a wide area in case of crisis by using aerial platforms, satellites and communication systems. This SA toolbox that was developed during the project allows for combining of useful data thus increasing the overall situational awareness.

## 2.4 Artificial Intelligence in ATM today

Artificial intelligence (AI) is defined as the ability of a digital computer or a robot to perform tasks commonly associated with intelligent beings [16]. Artificially intelligent machines were initially programmed to solve complex problems using if-then rules, as opposed to the conventional procedural code [17]. The result of such programming is a machine whose actions resemble the thought process of a human. However, artificial intelligence went through three major stages since it was first popularized in the 1950s, as further explained in Appendix C.

For an AI system to be used in ATM, it has to be verified and safe. The greatest threat to safety regarding using artificial intelligence comes from its lack of transparency. An artificially intelligent machine works as a "black box" in a way, since its inner process isn't in any way visible to humans. The safety mitigation of that threat is supervision of the AI application should it be impossible to open the black box to a satisfactory extent. There are methods to monitor and supervise artificial intelligence up to a point, such as:

- keeping a human involved, as either a part of the process (human-in-the-loop - HITL) or commanding it (human-in-command - HIC)
- using a traditional backup system (safety net)
- monitoring the AI through an independent agent
- joining ML with the conventional rule-based approach (e.g. Hybrid AI) [18].

### 2.4.1 AI vision in ATM

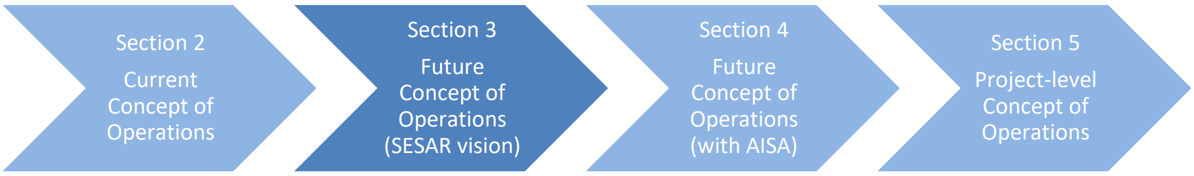
Many tasks in aviation performed exclusively by humans today can be automated in the future, taking the load off the human operators and enabling increased safety and adaptability in the air traffic system. Artificially intelligent systems are forecast to be implemented into the cockpit as well as ground systems, making way for air-ground machine-to-machine communication much more. The electrification trend will continually change aircraft characteristics and operations. Aircraft will evolve come new trends and new vehicle types, namely cargo and passenger drones. Artificial intelligence is expected to have a fundamental role in air traffic complexity management and airspace design, enabling more effective management of ATC resources based on improved predictions of demand. The current advancements in deep learning (DL) bring about a number of possible applications that could benefit aviation; in particular, computer vision and natural language processing (NLP) [18].

### 2.4.2 AI applications in ATM

The advancements in the fields of AI and ML have paved the path for a range of applications in ATM. There are projects where ML is already used in solving complex problems in every flight phase, starting at strategic up to tactical de-confliction and operations themselves. A few will be explained below.

- Time-based separation (TBS): Strong headwind conditions negatively effect flight operations of landing aircraft, which can result in delays and flight cancellations. Time-based separation, developed by SESAR, should reduce the intervals between consecutive landings in headwind conditions. The solution, already used in Heathrow airport, is being further enhanced by ML agorithms that refine wake separation minima by combining downlinked parameters from the aircraft. TBS has so far enabled an average of 20 extra landing aircraft daily at Heathrow. Accurate and real-time information on wind is obtained from aircraft Mode-S transmissions – but could also be obtained from alternative sources. The safety regulator was included in the research programme early on so the safety case could be developed and approved [18], [19].
- AIMEE is the Searidge advanced AI framework for the development of artificial neural network-based solutions for air traffic control and airports. In London Heathrow, it’s being used as a way of replacing air traffic controllers view of the runway in case of adverse weather conditions which reduce visibility. AIMEE can determine precise aircraft positionins using advanced AI segmentation algoriths. It informs the ATCO when the aircraft successfully cleared the runway. It’s implementation brings benefits in form of operational resilience, increased arrival capacity, especially in low visibility conditions, and reduce fuel burn and emissions [20].
- Trajectory prediction improvement (TPI): The TPI tool calculates the route an aircraft is most likely to fly, by training it by looking at historical flight data, as opposed to the filed flight plan. The benefits of the tool are better route prediction and a reduced lateral error by half compared to the filed route. It accounts for military areas, flight levels, airports, day of the week, etc. [18], [21].
- Take-off time prediction: There are two learning models that account for a number of factors to improve take-off time prediction of flight an hour prior to their Estimated Off-Block Time (EOBT). The models are trained using historical flight and weather data. Predictions show a 30% reduction on the take-off time prediction error compared to the Estimated Take-Off Time [22].
- Artificial Intelligence & Data Analytics for Air Traffic Management: The Singapore ATM research institute is developing a hybrid Human ATC paradigm that can benefit future ATM systems. It uses artificial intelligence and man-machine learning models that can assist human tasks in ATC. This model should assist human tasks in air traffic control, enabling the controllers to take on higher-order tasks, such as tactical air traffic flow management [23].

# 3 Future Concept of Operations according to ATM Master Plan




## 3.1 ATM Master plan roadmap

SESAR plans to deliver a traffic management system that is capable of handling growing manned and unmanned air traffic. This vision relies on the future of trajectory-based operations, delivering passengers and goods on time, and doing so in a cost-effective manner. This kind of future is based on the digital transformation of the entire infrastructure system, which will show a notable increase in both connectivity and levels of automation. The existing infrastructure is going to be more agile and modular which will allow air traffic and data service providers to operate more easily and to be supported by a wider range of services. The vision is to unify the entire European aviation network, instead of it being several segmented portions of airspace as it is today. All of these plans for digitalisation and automation will also significantly benefit the European economy and society as a whole while requiring a relatively small investment cost. The envisioned architecture can be seen in Figure 3 regarding current architecture [3].

Such digitally transformed aviation SESAR aims for is going to use information and data for automatisation and provide connectivity solutions in order to improve the performance in general. By doing so, the system will be safer, more efficient, and cost-efficient. Aviation will use the advantage generated by advanced digital technologies so it can generate some new services and optimise the current ones. It will also have in mind to deliver a better experience and greater benefits to all of its stakeholders. Nowadays, technological development is gaining tremendous momentum outside of the ATM. This future field of work (AI, autonomy, fast prototyping, etc.) allows for high-risk/high-gain research necessary in the digital sector. This requires a fast-paced and open approach to collaboration and greater coordination, in order to keep up with the pace of today and reduce the time it takes to reach the market [3].

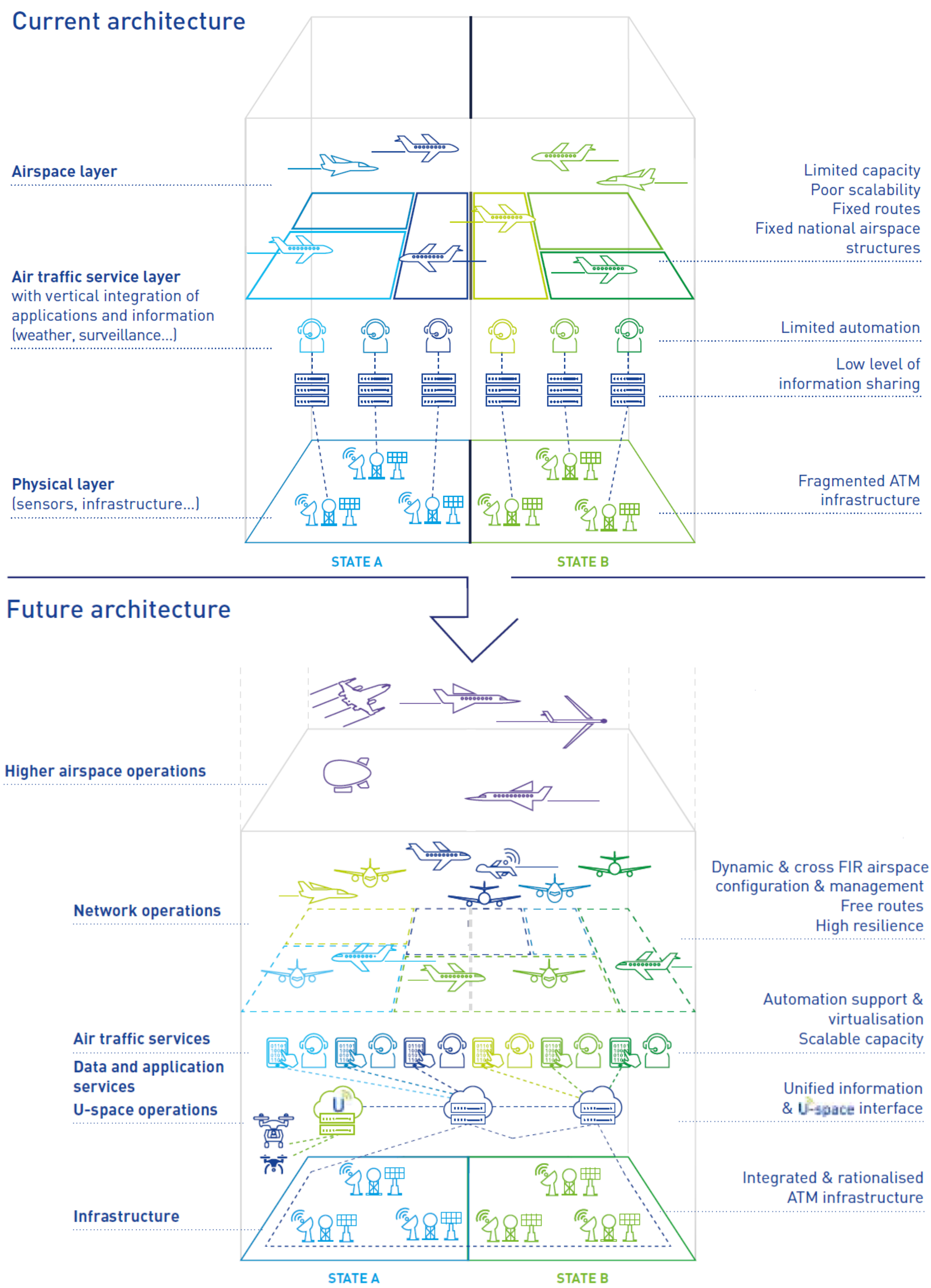



**Figure 3 Current and future architecture according to ATM Master Plan 2020 [3]**

Figure 4 is an introduction of the ATC automation model which is based on the classic model used by the experts in the SESAR program. It ranges from Level 0, which is low automation, to Level 5 or full automation. It is a plain view of all the levels of automation that are planned for each phase of the ATM Master Plan [3].

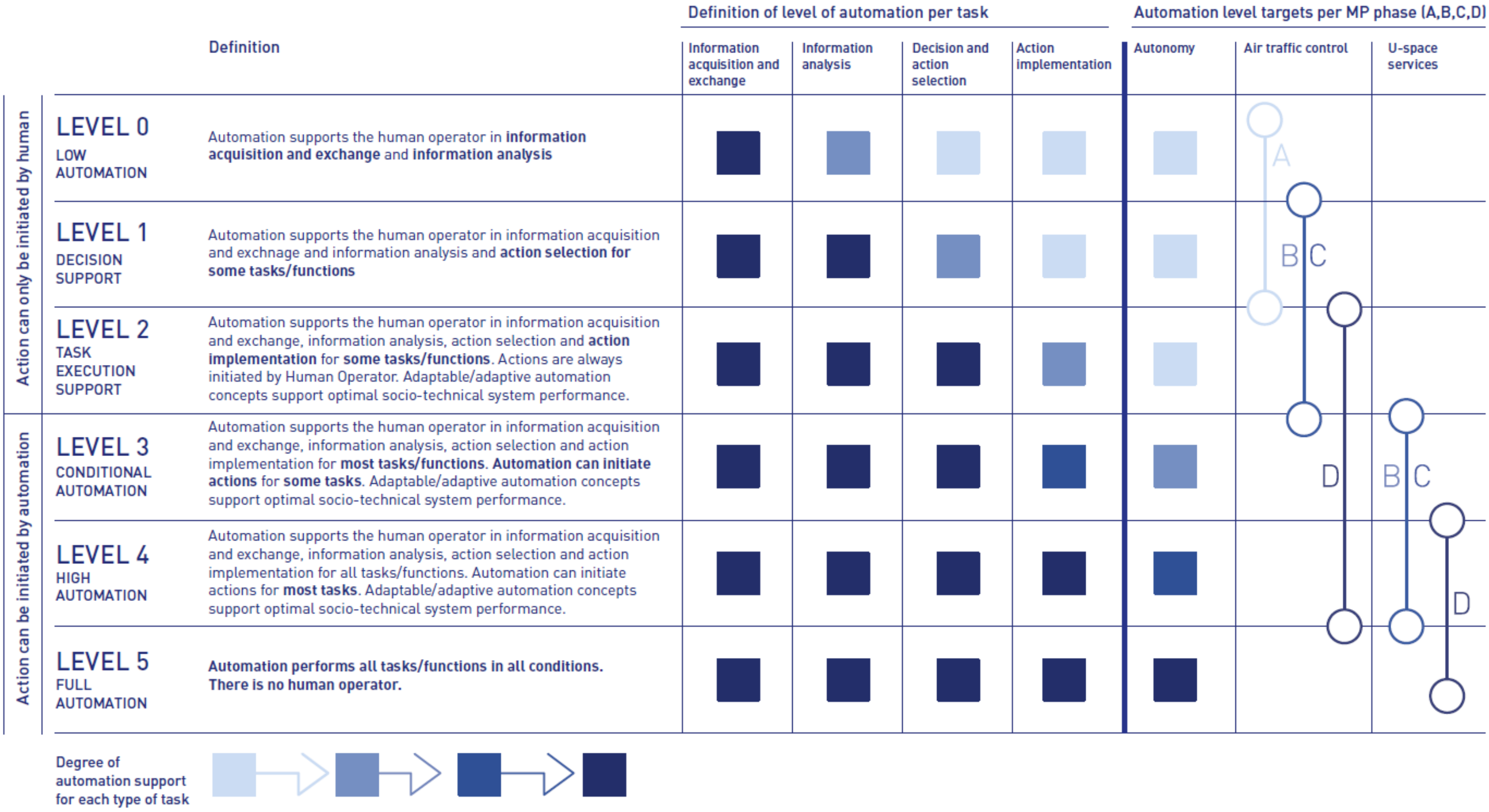



**Figure 4 Levels of automation [3]**

In phases A to C, the automation is going to focus on the increasing system support. In these phases, the initiation of actions still comes from humans. The big breakthrough is expected to happen in phase D where the human will be removed from the loop and delegated some tasks to give way to higher automation levels. Human limitations will now no longer be the main reason for the capacity issues of the airspace. Automation in this phase will also warrant a collaboration between humans and machine ATM agents. It is expected that the boundaries between ATC and Air Traffic Flow Management (ATFM) will start to blur as time passes, and automation will take on more of the tactical ATC tasks [3]. This four-phase approach to improvements is depicted below in Figure 5.

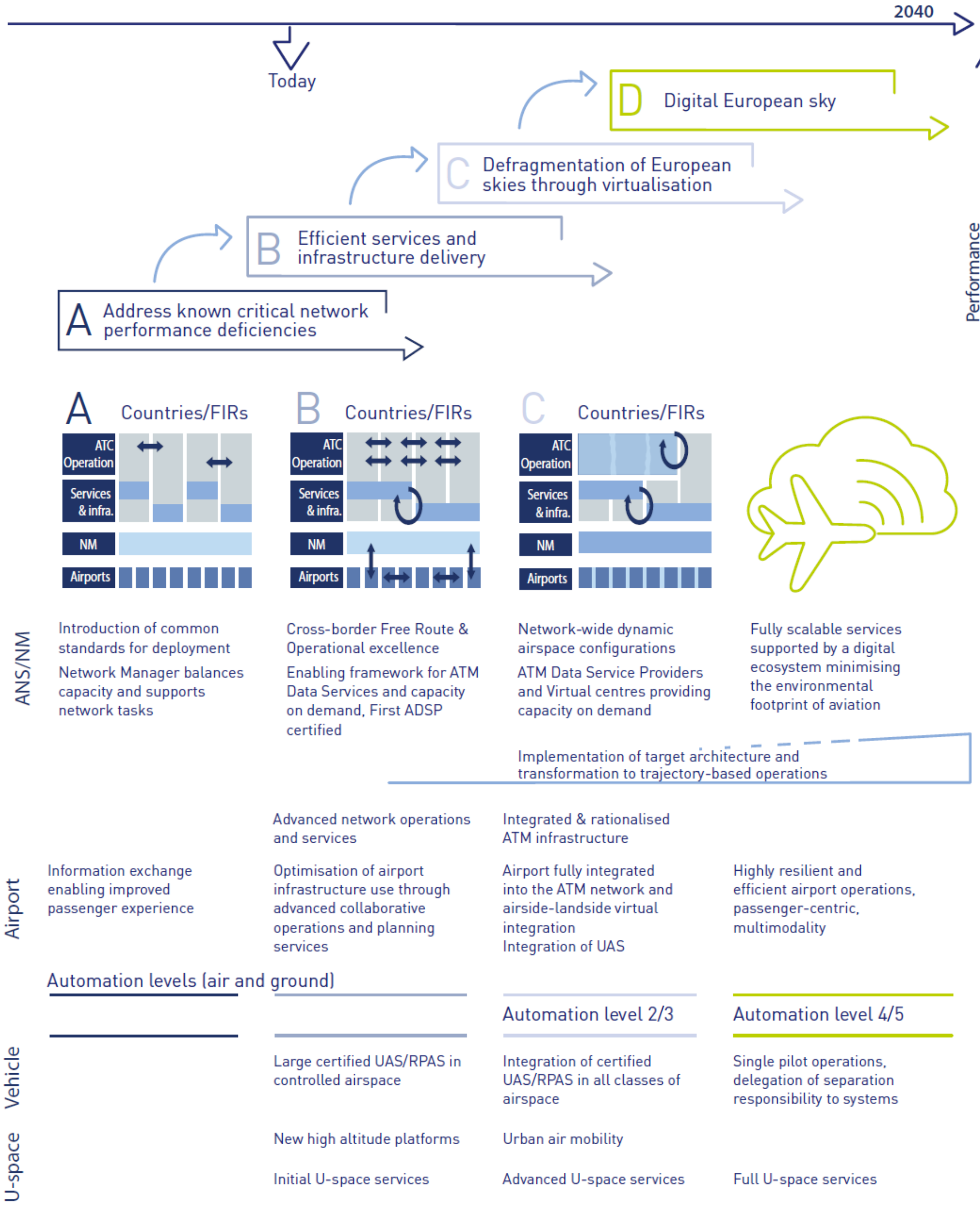



**Figure 5 Four-phase approach to improvements [3]**

In terms of modernisation, it is important to consider the role of the human and their interface with the machine. Great progress has been made in the machine learning (ML) and artificial intelligence (AI) fields which has already allowed usage of several applications in ATM. Many current tasks in aviation that are being executed by humans alone are going to be automated in the future, thus increasing the safety of air traffic. It is expected that AI systems are going to be integrated into the cockpit as well as into the systems on the ground. This will allow air-ground and machine-to-machine communication that can be used for trajectory management and more. There is going to be interlinkage between different actors in the loop (both human and machine) that will be working together in order to optimise the actors collaboration and the overall system performance. It is imperative that the system design is based on a thinking approach so that its performance is based on the understanding of task distribution and system dynamics. Certain requirements will have to be incorporated so that the human and machine actors can work together effectively across the entire system [3].

## 3.2 SESAR vision

What SESAR aims to deliver is a resilient ATM system that can handle the growing air traffic, manned or unmanned, and in all classes of airspace. This concept primarily has in mind trajectory-based operations (TBO) that will allow airspace users to fly efficiently and use flight trajectories they prefer. The so-called digital European sky is going to enable all of this as it represents a new architecture where everything is connected, all the ground and air resources. They are optimised across the network and do not differentiate regarding altitude, class of airspace or individual aircraft performance. This way it all feels like a huge well connected digital ecosystem. In such an environment, service providers are going to operate and collaborate as a big organisation. This new architecture is also more suitable with the future vision of ATM capabilities including new forms of air traffic [3].

### 3.2.1 The digital European sky

The world of aviation is rapidly changing and evolving, aircraft are now well connected, more autonomous and more intelligent. The passengers have even higher expectations than before regarding eco-friendliness and the number of options provided for them. The list of demands goes on: quick and reliable travel information (schedules, prices, punctuality) and even environmental impacts. A simple representation of the future system is depicted in Figure 6.

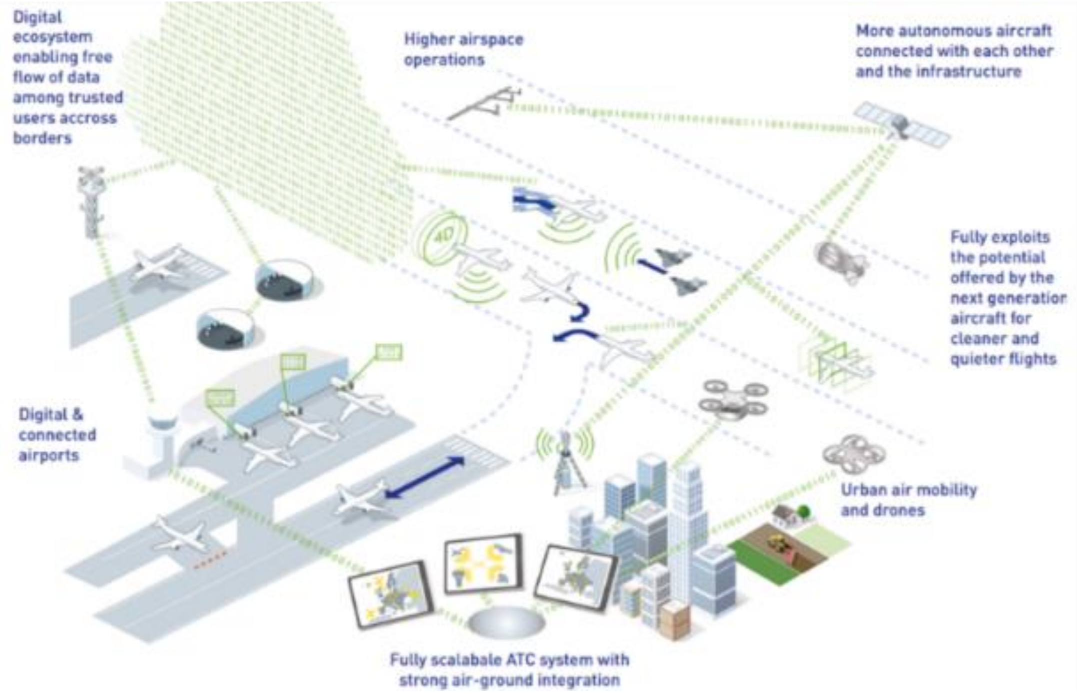



**Figure 6 Digital European Sky [3]**

By the year 2040, it is expected that the number of aerial vehicles will increase, and not just conventional aircraft but unmanned ones, such as drones, as well. TBO free-route operations will allow airspace users to improve the utilisation of their trajectories within the optimised airspace configuration. Such new structure will have to meet safety, security and environmental performance targets and be able to meet stakeholders needs. It is planned that the infrastructure is going to have to evolve alongside advanced digital technologies. All these innovativity and new concepts are going to influence the reduction of fuel and emissions, as well as the mitigation of noise impact. One of the goals is to conform to the European Union's (EU) policy regarding the transformation of aviation into an industry that is climate-neutral. As performance-based operations are planned to be fully implemented, mobility is going to take intermodality even further beyond, connecting different modes of transport as a smooth door-to-door service.

### 3.2.2 Four transitional phases

As it was mentioned before, the transition from current to future architecture will occur through four phases. In the first three phases, the automation is going to focus on increasing system support, but the initiation of actions still comes from humans. Phase D brings a breakthrough as the human will be removed from the loop and delegated some other tasks to give way to higher automation levels. The representation of these phases was previously shown in Figure 5.

Phase A is going to deal with the deficiencies of the critical network performance. This phase will enable TBO through a service-oriented architecture. The system-wide information management (SWIM) implementation will enable the sharing of data and information and introduce open architecture. Measures against cyberattacks will also have to be taken in order to ensure the system integrity. The improvement of communications is based on the mentioned SWIM, the automatic dependent surveillance contract/extended projected profile (ADS-C/EPP) and CPDLC. This first phase has already begun and includes the deployment of SESAR solutions.

Phase B encompasses efficient services and infrastructure delivery. A set of ATM data service providers (ADSPs) will help optimise and rationalise ATM support services, thus allowing the transition from physical to virtual infrastructures. Virtual infrastructures are automated and have increased data-sharing capabilities to enhance predictability in a way that remote provision of ATS becomes possible. This second phase relies on SESAR 2020 Research and Development (R&D) activities and solutions, as well as the evidence of performance gains that are expected Europewide.

Phase C focuses on defragmentation of European skies which will be achieved via virtualisation. By the time this phase comes into place, the ATM system will already be at a higher level of automation which implies higher productivity, connectivity and information sharing. TBO will be enabled which will allow for management and optimisation of flights as a whole together with collaborative planning and decision process. Further integration of ATC into air traffic flow and capacity management (ATFCM) and Demand Capacity Balancing (DCB) will make this possible. This entire integration is going to be gradual but it will allow Air Navigation Service Providers (ANSPs) to provide their end-to-end services and share resources regardless of national borders thus changing the current infrastructure.

The target vision of phase D is achieving a digital European sky. In this phase, it is planned to provide a system for both manned and unmanned aircraft with emphasis on safety. When this phase takes place the level of automation will have reached at least level 4 (see Figure 4). Considering the rise of the complexity of future air traffic, AI will have a significant role of support to both pilots and ATCOs thus reducing generated workload. ATCOs are going to be able to delegate a great number of tasks to the machines, and the system will be able to propose the best options to the human as well as solve complex trajectory situations. The network will be able to predict the traffic situation which will pave way for activation of capacity-on-demand services to avoid bottlenecks thus opening the possibility of air traffic without delays.

The possibility of the accomplishment of digital European sky goals for 2040 is not unattainable, but it is quite ambitious. It will require a whole new approach within SESAR to shorten the innovation and development cycles enough for them to reach the market on time. The only way to move forward and be able to cope with the growing demand is to introduce more daring changes that will help shape the aviation infrastructure of the future [3].

## 3.3 Performance view

The developments in ATM will require a thorough technological transformation in order to continue supporting safe operations in both controlled and uncontrolled airspace. By 2050, we will see a great change in air traffic, starting with the significantly increased number of vehicles and new types of vehicles, to having interactions between different types of traffic that is not necessarily human-driven (increased degree of airborne automation and unmanned cargo). The demand for lower-level airspace is rapidly increasing since more drones are flying every day, either for leisure or to deliver professional services. Current productivity makes managing those levels of traffic at levels unsustainable, taking into account the cost and the limited efficiency that can be achieved by splitting more sectors.

Furthermore, increased air traffic and new types of traffic are going to lead to unparalleled levels of diversity and complexity. These issues will require further automation to achieve full scalability of the ATM system and ensure a cost-efficient ATM system with increased safety levels [3].

While the European Union (EU) citizens experience benefits of continued growth, this growth corresponds to a serious environmental challenge in the immediate future. The aviation industry in Europe and worldwide is prompted to increase their efforts to address the issues regarding the environment and its sustainability concerning air travel. The goal of carbon-neutral air travel in the EU is set for 2050. SESAR is working hard to support this goal and is gradually contributing to the elimination of environmentally inefficient practices caused by the outdated aviation infrastructure.

This section lays out the performance ambitions assuming that planned SESAR solutions in phases A to C will be made available through research and development activity deployed on time and fully used. These ambitions mostly refer to the European Civil Aviation Conference (ECAC) area and correspond with the 2035 target date. The performance ambitions are divided into categories according to the SES Key Performance Areas (KPAs): capacity, safety, environment and cost-efficiency. Figure 7 is a graphical representation of the performance ambitions with specific values in the defined KPAs [3].

| | | | Performance ambition vs. baseline | | | |
|---|---|---|---|---|---|---|
| Key performance area | SES high-level goals 2005 | Key performance indicator | Baseline value (2012) | Ambition value (2035) | Absolute improvement | Relative improvement |
| Capacity | Enable 3-fold increase in ATM capacity | Departure delay[4], min/dep | 9.5 min | 6.5-8.5 min | 1-3 min | 10-30% |
| | | IFR movements at most congested airports[5], million | 4 million | 4.2-4.4 million | 0.2-0.4 million | 5-10% |
| | | Network throughput IFR flights[5], million | 9.7 million | ~15.7 million | ~6.0 million | ~60% |
| | | Network throughput IFR flight hours[5], million | 15.2 million | ~26.7 million | ~11.5 million | ~75% |
| Cost efficiency | Reduced ATM services unit costs by 50% or more | Gate-to-gate direct ANS cost per flight[1], EUR(2012) | EUR 960 | EUR 580-670 | EUR 290-380 | 30-40% |
| Operational efficiency | | Gate-to-gate fuel burn per flight[2], kg/flight | 5280 kg | 4780-5030 kg | 250-500 kg | 5-10% |
| | | Additional gate-to-gate flight time per flight, min/flight | 8.2 min | 3.7-4.1 min | 4.1-4.5 min | 50-55% |
| | | Within the: Gate-to-gate flight time per flight[3], min/flight | (111 min) | (116 min) | | |
| Environment | Enable 10% reduction in the effects flights have on the environment | Gate-to-gate $CO_2$ emissions, tonnes/flight | 16.6 tonnes | 15-15.8 tonnes | 0.8-1.6 tonnes | 5-10% |
| Safety | Improve safety by factor 10 | Accidents with direct ATM contribution[6], #/year Includes in-flight accidents as well as accidents during surface movement (during taxi and on the runway) | 0.7 (long-term average) | no ATM related accidents | 0.7 | 100% |
| Security | | ATM related security incidents resulting in traffic disruptions | unknown | no significant disruption due to cyber-security vulnerabilities | unknown | - |

1 Unit rate savings will be larger because the average number of Service Units per flight continues to increase.
2 "Additional" means the average flight time extension caused by ATM inefficiencies.
3 Average flight time increases because the number of long-distance flights is forecast to grow faster than the number of short-distance flights.
4 All primary and secondary (reactionary) delay, including ATM and non-ATM causes.
5 Includes all non-segregated unmanned traffic flying IFR, but not the drone traffic flying in airspace below 500 feet or the new entrants flying above FL 600
6 In accordance with the PRR definition: where at least one ATM event or item was judged to be DIRECTLY in the causal chain of events leading to the accident. Without that ATM event, it is considered that the accident would not have happened.

**Figure 7 Key performance indicators [3]**

### 3.3.1 Capacity

*Challenges of Growth* by Statfor forecasts an increase of unaccommodated flights in 2040, which would result in a nine-fold growth of passengers whose flights will have been delayed compared to 2018 numbers. The goals for capacity are to significantly reduce ATFM delays with improved potential for fuel-efficient trajectories, as well as to find a way to accommodate all traffic forecasts in the „Regulation and Growth“ scenario [3].

### 3.3.2 Cost efficiency

Some of the SESARs solutions are aimed at improving ANS productivity. The goal is to implement needed technical system changes with a reduced life cycle cost, while also working on developing operational concepts that would improve the productivity of ANS provision. In addition to those concepts, Fulfilment of these cost efficiency improvements will also require operational changes. The extent of achieving the cost efficiency goals will depend on the degree of SESAR solution deployment [3].

### 3.3.3 Operational efficiency

The reduced departure delays and more efficient flight paths are planned to result in indirect economic benefits for flight operations by reducing fuel consumption and gate-to-gate flight time, as well as improving predictability. When it comes to the military, the operational efficiency goals are synonymous with mission effectiveness achieved by optimal adherence between the planning and the execution part of the mission [3].

### 3.3.4 Environment

The strategies to improve the environmental performance ambition look at both the global and the local picture. The global performance goal in average CO2 emission reduction per flight is 0.8-1.6 tonnes. When it comes to individual airports, aviation accounts not only for the CO2 emission but also noise pollution. The environmental issues are unique for each airport due to specific airspace constraints and the traffic mix. For that reason, greater emphasis should be placed to innovative solutions which would allow airports, ANSPs and airspace users to optimize trajectories. Other than optimized trajectories, another strategy used to work towards meeting the environment KPI goals is innovation in aircraft and engine design, such as continuous climb and descent operations, curved, steep and/or segmented approaches and noise preferential routes [3].

### 3.3.5 Safety

Safety is a driver for improvement in ATM. A great number of planned solutions focus solely on improving safety performance. However, every proposed solution, even the ones that don’t directly address safety performance, are subject to safety assessment prior to deployment. All of the safety improvements will be implemented under the European Plan for Aviation Safety to allow for improved efficiency in achieving safety and efficiency goals, as well as to lay the groundwork for a unified aviation risk management framework. Safety ambition is to have no accidents that come as a result of ATM/ANS [3].

### 3.3.6 Security

The overall objective of this KPI is to ensure adequate protection of the ATM system and ATM data against security threats. Security risk management supports the ATM community and provides safe, quick access to the system and information. One of the focal points of security risk management is preparing for the event of (cyber)security threats to aviation to avoid jeopardizing operational safety of disrupt operations [3].

## 3.4 Digital AIM and MET services

For TBO to be fully implemented all actors must share data and information. All important aeronautical and meteorological information has to be made available to everyone simultaneously. This will have to become the norm of the future as the use of airspace and other ATM resources will become more dynamic. Meteorological service for air navigation (MET) and Aeronautical Information Management (AIM) need to be digitalized. This will allow for the implementation of new services that will provide static as well as dynamic information in a digital form that will be usable by humans and the ATM systems. These services will be compliant with SWIM and will allow for the use of AIM, MET and other important operational information. Such information will also be available within the aircraft for representation and interpretation [3].

In regards to the SESAR solutions, a digitally enhanced briefing is suggested as a means to unify the mentioned improvements. The quality and usability of aeronautical and meteorological information will be improved using aeronautical data. Such information will be made available to pilots, flight dispatchers and ATCOs throughout the entirety of the flight. Currently in the works regarding automation and digitalisation are the static aeronautical data service and aeronautical digital map service functions. They will be used by various ATM systems, such as safety nets, to provide data in a digital form. What comes out of these functions is a data set, whose subsets can be accessed with a different request: certain geographical areas, attributes or even some functional features. A key to these solutions lies within the availability of information, and those will be provided by aircraft carrying an AIM/MET sensor. They will collect meteorological data, ADS-C related information and CNS status information which will be used to enable the improvement of airspace users situational awareness, as well as trajectory management and decision-making [3].

## 3.5 Traffic complexity resolution

The air traffic control operation in any control centre today is based on dividing the airspace into several sectors – three-dimensional regions or airspace stacked above each other at defined altitudes. As a consequence of this fragmented operation mode, each control centre's capacity is constrained by its sector with the minimum capacity. The total capacity of a control centre could be raised if traffic complexity bottleneck areas were identified before they became congested. That way, traffic patterns could be reorganized to more evenly balance the complexity between the available sectors.

The presented issue triggered developing the concepts that address with multi-sector planning, based on traffic complexity management (TCM), where tools for predicting traffic complexity over several sectors have been developed. They help manage the general complexity by forecasting peaks and proposing alternatives to the FMP. The traffic complexity of a sector is an evaluation of ATCO's workload at the sector. For traffic complexity resolution, it is defined using the number of flights within the sector, near its borders and on nonlevel segments within it. The reason is that each of those positions requires special attention and procedures from the controller.

Complexity resolution is defined as the dynamic modification of flight profiles to decrease the predicted complexity in a sector over a set time interval, in that way avoiding unacceptable peaks of ATC workload. In the multi-sector structure, the effect of complexity resolution is also to balance the complexities of several neighbouring sectors, leading to avoided intolerable dips at ATC workload and a more fair division of workload between those sectors [24].

SESAR is working on developing advanced software that can estimate traffic demand and complexity using continuously updated information from several sources, which should replace the non-integrated tools used today. FMP as a local level can modify capacity by applying predefined complexity metrics. This results in a more predictable air traffic flow, fewer delays and improved safety [25].

## 3.6 Trajectory Based Operations

Trajectory-based operations (TBO) allow the ATM system to know and, if needed, modify the flights' planed and actual trajectories. The modification can happen before or during flight, and it is based on precise data shared between all stakeholders. That requires for all flight information to be integrated for a synchronized view of data by all users involved [26].

4D trajectories (4D – latitude, longitude, altitude & time) relate to both cockpit and ground system evolution planned within SESAR innovations. It links to TBO in regards of sharing the same aeronautical, weather and 4D trajectory information. The future lies in unified and global trajectory sharing which will enable significant benefits in flight management. The goal is to be able to view all flight trajectories among stakeholders, including the forecasted meteorology and the airspace configuration. These solutions will increase both safety and efficiency as part of the SESAR goals [3].

In regards to SESAR, 4D trajectory management is a key to the improvement of air traffic operations, with its essential aspect being the synchronization of air and ground trajectories, which enables better balancing of tactical and strategic separation management. The research and development activity in this area supports both tactical separation provision using tactical tools (with a look-ahead time of 6-7 minutes) and ATCO tools which support planning activities related to separation provision with a longer look-ahead time.

4D trajectories data contains all relevant information and is automatically made available to all the relevant stakeholders, thus improving situational awareness. By using TBO, it will be possible to adjust airspace characteristics according to the predicted demand, as well as fully benefit from the civil-military collaboration [27].

## 3.7 Free Route Airspace

Free route operations are expected to be possible in airspaces of all complexities, including those of high complexity. Thanks to the introduction of high automation, certain processes will be less complicated. The airspace will be managed as a continuum with implemented automated tools that will help in conflict detection and resolution, coordination, and flight monitoring. It will allow for the implementation of dynamic airspace configurations and flight-centric operations. It will bring benefits in terms of capacity, support, and Demand Capacity Balancing (DCB), as well as offer greater flexibility of flight optimisation. Cross border FRA is planned to be at a sub-regional level and implemented during day and night (H24), and even include high complexity areas to provide coverage for all flight phases. In the best-case scenario, FRA will also be implemented in lower airspace which would cover the airspace from Terminal Control Area (TMA) exit to TMA entry. The goal of lower airspace usage will significantly improve time and fuel efficiency for short-haul flights [27].

FRA's main objective is to provide AU with an opportunity to optimise their flights, however, to ensure safety some airspace characteristics still need to be defined. The reduction of constraints and flight optimisation will be accomplished with the help of advanced automated support tools. Advanced planning systems will be able to plan the most flight cost-efficient route in the future. Although the main goal of FRA is naturally for AU to choose their own route, some waypoints will have to remain within FRA for ATCO and AU use. FRA is already widely implemented throughout Europe, with varying results of the intended usage. But as of the 1st of January 2022, its implementation will be mandatory at and above FL310 [27].

## 3.8 Dynamic Airspace Configuration

Dynamic Airspace Configurations DAC is a concept used for optimisation and coordination of airspace reservations (ARES) and the ATC sector configuration. The goal of DAC is to enhance support for sector design and configurations to achieve a coordinated single sky. Such a thing is accomplished by designing, planning, and managing certain capacity elements dynamically and flexibly. This concept will integrate Airspace Management (ASM), ATS, and DCB through Collaborative Decision Making (CDM), and all of this will be supported with automated tools. This concept will take into consideration some new aspects as inputs, the hazard zones, to encompass significant weather [27].

Since airspace architecture is used as a basis for sector configuration planning, this provides new sector configuration possibilities. It will be possible, using ARES activations, to compose the airspace, sectors, and routes into a uniform coordinated continuum. The trajectory data will aim to fulfil the military requirements and minimise the impact on the ATM network. Automation and new modelling capabilities are a must for this complex environment. To provide a DCB solution, it is important to integrate DAC with 4D targets. Capacity will be optimised so it can meet with the adjusted demand. During the planning phase, CDM processes merge ASM and DAC to achieve DCB and help with ATC planning. There will be increased efficiency and improved ATM resource management as a result. It is also important to note that a certain percentage of civil and military aircraft are not equipped or just partially capable of such operations in TBO, and will require handling [27].

## 3.9 Flight Centric ATC and Multi-Sector Planner

Since the European airspace is divided into FIRs, which are further divided into sectors, adding more ATCOs into the equation to increase capacity is no longer viable. If those current barriers are torn down and allow for the structure to no longer be reliant on geographical structures, then there is an opportunity to even out the air traffic. Flight-centric operations are a great way of optimising the use of the existing airspace and will allow the airspace users to fly more efficient routes. Flight-centric ATC will use automated support to. Instead of just managing the traffic in a single sector, this so-called sectorless ATM concept will allow the ATCO to be responsible for a certain number of aircraft instead. Flight-centric ATC has been in the works since 2008 and is currently in the pipeline as a SESAR project named PJ10 PROSA. The management of aircraft in this concept will encompass their flight segment along traffic flows or simply within larger airspace. This new concept will significantly impact conventional communications between pilots and controllers, not to mention the coordination procedures. The basis of such airspace allocation is on the assignment of arrivals to one ATCO team, and the departures to another team. New tools will have to be developed to be able to coordinate and allocate the traffic in this new solution, as it will be of utmost importance to establish responsibility for the resolution of potential conflicts. Since the flight-centric solution will require constant longer than usual communication with the aircraft, communication tools will also have to be reviewed which might require multiple VHS antennas. However, it already has some promising benefits: optimised workload distribution between controllers and reduced coordination workload between ATCOs in a single controlled area and even adjacent areas [3], [27], [28].

Another solution for the growing traffic is to introduce a new role to ATC. The proposed concept would replace the planner with a Multi-Sector Planner (MSP). The MSP would take over the planner's tasks, but would also be responsible for a set number of adjacent sectors (Multi-Sector Area – MSA; see Figure 8). The MSP's priority would be to balance out the workload among sectors in his jurisdiction. MSP is not a new term, it has been an option for some years, ever since the Program for Harmonized ATM Research in EUROCONTROL (PHARE) first launched in 1989 [29].

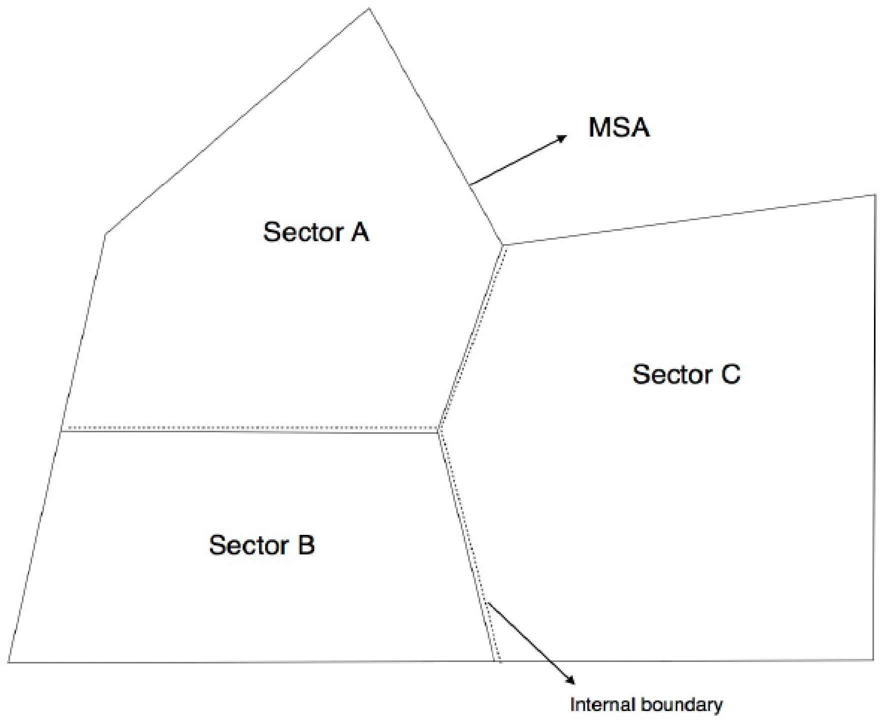



**Figure 8 Example of a Multi-Sector Area [29]**

The PHARE concept had in mind a more layered planning system. They wanted to connect the ATFM level planning with control of the aircraft in the sector. Since executive controllers can only plan minutes ahead of potential conflicts, compared to ATFM that plans hours ahead, an MSP is necessary to mediate and offer strategic solutions to overcome the generating complexity. In the future environment, the EXE will not be the only one resolving conflicts, as the MSP will help prevent them altogether, in a greater scope than it has been so far. In order for the MSP to perform their duties, they need to have appropriate tools. One such tool developed to assist them is the Tactical Load Smoother (TLS) which was also developed as a part of the PHARE program. The TLS gives the MSP certain information about the predicted future complexity and generates indications of times and places where such complexity is necessary to be dealt with in advance [30]. According to SESAR ConOps 2019, the MSP in en-route can handle and work with a maximum of 2 executive controllers, as more would not be feasible.

## 3.10 Advanced Demand Capacity Balancing

Optimized ATM Network Services seek to achieve SESAR goals of increasing ATM capacity and coming up with better opportunities for stakeholders to improve their operations in terms of operational efficiency and environmental gains. This is planned to be achieved by fully integrating DAC with DCB, as well as dynamic DCB with ATC planning, alongside Queue Management. This new operation is necessary to support optimized trajectories in an airspace environment that encompasses Free Route, Flight and/or Flow-Centric operations, and use of Collaborative Control. Trajectory management is the core of effective DCB across the planning and execution phases, making full use of iterative development of the 4D trajectory. Airspace users will be given new opportunities to become involved and to better manage their business needs within the complete DCB process due to the increase in information quality, improved accuracy of demand forecasting, together with the shared view and interface between DCB actors [27].

To ensure stability and performance of the network, the integration and necessary coordination of constraints to approach demand versus capacity imbalance is required. Constraints are generated by numerous sources, such as airports, ANSPs, AUs, and NM. The integration of those constraints is achieved using new rules and mechanisms that replace the traditionally used „first-planned/first-served" slot allocation. Each stakeholder, particularly the Airspace User, can get a comprehensive view of all constraints through Holistic Planning Management. It provides the opportunity to reach the global optimum among the different stakeholders' requirements. Airspace Users' chosen trajectories are included alongside costs associated with the deviation, as well as ATM Planning constraints issued for Airport optimisation, ASM, DCB, ATC sequencing, and flow optimization. Holistic Planning Management evolves through time from planning to execution, with all the actors being able to use the tools as required and are always able to consider the network view [27].

The Network Impact Assessment functionality allows the stakeholders to assess and evaluate the effect of their intentions and decisions, with built-in support of what-if capability. This capability is scaled up to provide problem resolution using numerous scenarios across the ATM planning spectrum. Those scenarios and related tools come with different levels of detail appropriate to the task at hand. Stakeholders have query mechanisms and what-if functionalities at their disposal, which provide them with information necessary to support their needs such as 4D trajectory planning, DCB decision-making, and approval processes. That leads to enhanced collaborative decision-making (CDM) and finally improved stability, with a decreased coordination need for strategic tasks to be included in the execution stage [27].

The complete DCB solution comes with the integration of DAC and 4D targets. It includes the enhanced adaptation of the capacity to meet a minimum adjustment of demand. Repetitive and integrated CDM processes integrate ASM and DAC into advanced DCB and ATC planning, moving from regional to sub-regional and local levels in the planning phase. That results in an improved ATM resource management, as well as increased efficiency for airspace and ground resources alike [27].

## 3.11 Cybersecurity and the human role

When it comes to the digitalisation of aviation, it is necessary to mention all the new emerging technologies. Those are data analytics, new security technologies, but also AI (pertaining analytics, machine learning, and deep learning). Such novelties underline the need for expansion of the area of cybersecurity considering arising threats. There could be many undesirable effects if the vulnerabilities of the new system are exploited. Safety, capacity, environment, and cost efficiency could be impacted, not to mention the delays. That's why the changing demands on ATM require a drastic increase in terms of system dynamics to secure the scalability and resilience in a way that all air traffic remains safe and efficient, under any given circumstances. To achieve this, digitalisation and automation are going to be of utmost importance. New tools will be essential to enable actors to distinguish between system failures and cyberattacks because aviation, air transport, and ATM are starting to look like attractive targets for cyberattacks since cyber-threats have become a part of our reality [3].

In the context of automation and digitalisation, the role of humans and the human interface with machines need to be taken into consideration. It is imperative to properly develop and define the human role taking into consideration the ATM concepts and technological developments. To support the human-system integration into the ATM system, there are going to be some key aspects. Following the new work system, new roles will also emerge in addition to the existing ones and such changes will have consequences, mainly the coordination between the system actors (human or machine). The new work system will have to provide new tools to support the system-wide situational awareness at all times, even during degraded modes of operation or cyberattacks. Therefore, these tools must also be implemented with the resilience to cyberattacks and technical failures. Humans will still have to make effective decisions, including when the joint intelligence modes of decision-making are used. Having that in mind, a different approach to defining the role of human will be required as it will differ from the one used in the past [3].

The entire work system design will be based on the thinking approach, where performance derives from the capacity to fully understand task distribution and system dynamics. As the work system itself is still evolving, it is not yet possible to describe the changes in the human role. However, the potential exists for the redistribution of tasks and functions between the actors and the new roles. With regards to that, the traditional modus operandi in which the human manages unexpected events unaided is simply no longer feasible. In some cases, responsibilities that were usually assigned to human roles (e.g., pilots and ATCOs), will change. Machine actors are probably going to take over a large number of tasks, mostly mundane simple ones, while the human actors will deal with more managerial and complex tasks. Such competence and capabilities will only be achieved through continuous in-depth technical training [3].

## 3.12 Operational scenario settings

**Digital AIM and MET services** fall under Essential operational changes (EOCs) and are a precondition for TBO. Developments in new or enhanced aeronautical (AIM) and meteorological (MET) information will also improve the information needed in a full 4D trajectory flight. The planned trajectory can be initiated much earlier with AIM and MET forecasts available many days in advance. For an ATCO this means a better situational awareness that comes from SWIM information sharing, enabling provision and reception of data including MET and AIM. MET and AIM information is provided to the SWIM network to support all actors in en-route related operations. The system capability mainly targets a „time to decision“ horizon between 3 minutes and 7 days. Such information will be displayed to ATCOs in a digital form warning them for example of hazardous meteorological conditions and suggesting tactical avoidance. This MET and AIM information will also support the SA tools and will be able to warn the ATCOs in a form of concise information on the display that affects en-route related operations. MET and AIM information is going to be consistent and coherent with other operational user environments and easily accessible for SWIM users. All this is currently in the development phase and is awaiting deployment in a period from **2022 to 2032** [31]. As far as the **2040/2050** horizon goes, full implementation of these changes is expected. ATCOs will become used to receiving relevant information via their displays and react accordingly. Learning about these benefits that are a sort of a safety net will be achieved through training so that new ATCOs can be taught how to utilise the given information. Perhaps it will even be possible to set a wider or narrower „time to decision“ horizon to better fit individual ATCO's needs.

**Traffic complexity resolution** implies the provision of an automated interface between local flow management, the NM and ATC planners which will assist controllers in reducing traffic complexity, traffic density and traffic flow problems. Previous trajectory and network information, as well as recorded analytical data from past operations, are going to be used for predicting traffic complexity and potential overload situations. This will allow for utilisation of mitigation strategies on network levels, but also on a local one which includes ATCOs. Extended Flight Plan (EFPL) will enhance the quality of the planned trajectory information which will, in turn, enhance flight planning and complexity assessments. The ATC team will be supported via automated tools that will help them in identifying, assessing and resolving local complexity situations in a way ATCOs are used to since they should be similar in user-friendliness to other automated tools used. These tools will continuously monitor and evaluate traffic complexity to predict upcoming congestions and reduce complexity by de-conflicting and/or synchronising traffic flows. It will be designed to support ATCOs by identifying complex situations, warning the ATCO about it and offering the solution for it via display presumably. This solution is expected to be implemented fully by **2027** [32]. When talking about **2040/2050** horizon, it is safe to presume that local planning by ATCOs will not be necessary as these tools will help resolve possible congestions and complex situations much earlier ahead using EFPLs to plan trajectories in a way that will allow for efficiency but also reduce complexity to a level where not much ATCO involvement is required.

As **4D trajectory** is implemented, target times and trajectory information will be improved which implies fewer tactical interventions and enhanced de-confliction. It will be possible to establish in advance an aircraft sequence for a merging point which will require constant coordination between aircraft and ATC ground systems. This will alleviate ATCO's workload, increased SA and the only difference for an ATCO will be increased monitoring of less complex and more predictable airspace. **TBO** incorporates 4D trajectories that are shared among users and provide them with up-to-date information indispensable for global decision-making. TBO is also one of EOCs, and with it, an ATCO no longer has to be focused on where the aircraft is, but on where it will be. The envisioned collaborative planning and decision-making process will enable each flight to be managed as a whole instead of segmented. Both pilots and ATCOs will be able to share consistent information throughout the trajectory. ATCOs will be able to access this information via SWIM. During the execution of RBT, ATCO will be able to provide input and rely on new technology to help them secure sufficient separation (such as ADS-B IN/OUT and ACAS Xa) [3]. Although all these new technologies exist and TBO is both in the **2035** and 2040 horizon, while it slowly rolls out there is going to be both TBO and non-TBO in the European sky. This is something ATCOs will have to look out for as they decide how to handle potential conflicts, probably favouring the TBO trajectories. For the **2040/2050** horizon, it is expected for all trajectories to be TBO-based, thus reducing the ATCO's workload, increasing monitoring tasks and improving the general SA by looking further ahead and solving potential conflicts way ahead of time.

**FRA** provides significant opportunities for airspace users. They can optimize their associated flights according to individual operator business needs and military requirements. For an ATCO, allowing more freedom to airspace users in terms of planning their trajectories implies a heavier workload. Controller workload increase due to individual trajectory interactions in a free route airspace environment should be atoned for with controller tools for conflict detection and resolution. FRA includes the implementation of dynamic airspace configurations and flight centric configurations.

Changing the shape and volume of sectors and utilising dynamic resizing will enable equal distribution of ATC workload across the sectors within a single centre/FAB. It's a countermeasure to handle complexity in very busy airspaces that could get so high, it wouldn't be possible to manage it using conventional ATC means. Dynamic airspace configuration is only possible using automated systems that continually evaluate traffic complexity and propose optimum solutions. The controller working position (CWP) is going to support the operating environments. Also, ATC systems will be updated with flight data downlinked from the aircraft (ADS-C EPP). FRA is already widely used throughout much of northern, south-east and central south-east Europe. As of the 1st of January 2022, implementation FRA will be mandatory at and above FL310. It is expected that most of the European airspace will have implemented FRA by the end of 2022. In the **2035** timeframe, FRA will have been tried and tested in the entire European airspace. In the **2040/2050** timeframe, FRA will possibly be encompassing a smaller number of large airspaces over entire Europe as a result of merging separate Free Route Airspaces into bigger ones.

**Dynamic Airspace Configuration** is planned to enhance support for sector design and configurations to achieve a coordinated single sky. This is accomplished by designing, planning, and managing certain capacity elements dynamically and flexibly, using automated tools that generate the optimum sector design and configurations. It will integrate concepts and procedures in order to allow for dynamic modification of flexible sector boundaries based on AU's demand. DAC has been tested in gaming, human-in-the-loop and real-time simulations and achieved positive feedback from the participants regarding operational feasibility, procedures, workload and situational awareness. FMP's and supervisors get to use a tool that's developed to build, assess and compare various airspace configurations to help their decision-making process. The sector configurations calculated by the tool are relevant and operationally feasible. ATCO's will be notified of the upcoming change in sector configuration 10-15 minutes in advance to maintain situational awareness. ATCO's will also have an aid tool to support their visualization of the sector configuration changes. The DAC project recognizes the importance of training for its successful implementation, therefore, the ATCO's will complete training to work in many different configured sectors and the knowledge of related operational procedures. ATM Master plan predicts implementation of the system by the end of 2032. It is not realistic to expect the system to be fully operable and deployed in all ANSPs in the **2035** timeframe, as each might have different priorities. In the **2040/2050** timeframe is likely that DAC will be used regularly throughout Europe.

To implement **Flight Centric ATC,** new tools will have to be developed to coordinate and allocate the traffic. Establishing responsibility for the resolution of potential conflicts is of the highest importance in this solution. A central allocation system will enable distributing the workload between controllers and reduce coordination between ATCOs regardless of their position. When there is a conflict, it is important to know who is responsible for the resolution in order to ensure that safety is never endangered. When traffic density is high, advanced conflict detection and resolution tools are needed. They'll provide long look-ahead time and designate conflicts to ATCOs. Communication is also under revision as this solution requires the aircraft to stay in communication with the same ATCO for a longer period than currently. This will likely need the involvement of multiple VHF antennae or digital voice communications over Internet Protocol (VoIP). The solution will be ready by 2033, according to the eATM portal, with the final five years of development focused on communication. The **2035** timeframe will witness Flight Centric ATC in certain areas in Europe, but its full implementation across Europe is a more realistic goal for **2040/2050.**

The **Multi-Sector Planner** brings about a new structure of teams and new procedures that will allow the planning controller to assist several tactical controllers working in different adjacent sectors. In en-route operations, a single planner controller plans and organises the traffic flows for two tactical controllers. Each of those ATCOs controls a different sector. The Tactical Load Smoother (TLS) provides the MSP with certain information about the predicted future complexity and indicates of times and places where the complexity is expected, for them to deal with it in advance. Another solution facilitating multi-sector planning is collaborative control, meaning coordination should only be an exception rather than a procedure. It is enabled by advanced controller tools that can combine sectors into multi-sector planner teams. MSP is a local objective that does not have a mandatory implementation deadline, though the end of 2024 is given as guidance. **2035** will see MSP implemented in some states in Europe. By **2040/2050** timeframe, depending on the proven feasibility, MSP might become a widespread solution with mandatory implementation in all ECAC states.

**CNS Infrastructure and Services** are an Essential Operational Change (EOC) and their communications part is quite relevant to the future of area air traffic controllers. Even though voice communications are currently the most used means of communication between pilots and ATCOs, datalink will soon take over. Voice communications will still be used for some non-critical and non-routine messages that are not time-sensitive when looking at the shorter **2035** horizon. When addressing long-term changes, **2040/2050**, VHF voice communication is expected to be almost fully decommissioned. Digital mobile technology (such as IP-based data and digital voice) is the future of air-ground communication and it will ensure that voice services are maintained alongside datalink. Some new voice connection functions can also be expected where it will be possible to enable voice exchange that will take place from anywhere, breaking down our current barriers [3].

Regarding the 2035 and 2040/2050 timeframe, it is safe to say that there is a common goal for all the SESAR solutions. The closer horizon aims for the new technologies and systems to start being implemented across the European sky. The system is the one that monitors the situation and warns the ATCO of possible interventions. At this time the ATCO is responsible for most tasks and is working actively with the help of the system that only serves as a safety net. The system only gives out warnings and suggestions to the ATCO for them to react accordingly. When talking about the 2040/2050 horizon, things change. The automation will be able to carry out tasks, but tasks could also be performed by human controllers to keep them in the loop and avoid or minimize de-skilling. Since the automatisation has reached high levels at this point in future, the system is capable of making decisions on its own without the ATCO input, thus optimising the air traffic and simplifying and unburdening the ATCOs workload. In the 2040/2050 timeframe it is possible that AI committee-like decision-making might take place with mutliple independently developed AI 'voting' on solution to a particular problem, not unlike multiple inertial navigation systems are used today. Human role in that case would be to manage the extremely unlikely situations when the complete system fails.

The tables below put the tasks performed by the ATCOs today in comparison with the imagined future tasks enabled by the tools and technology that are a part of the described SESAR innovations. They are in correlation with the Tables 1-3 of this ConOps as the previously explained tasks are now given predictions for the future implementation of innovations. The list of tasks is partially adapted from [12], however, the remaining contents of the tables were produced during this project.

| Current procedural tasks | SESAR innovations | Task after implementation | Tools |
|---|---|---|---|
| Detect planned flight | FRA, TBO, digital AIM and MET | **2035:** Flight is continuously being tracked by the system. Flight's trajectory is being updated and shared with all stakeholders as soon as any change is made. Automated detection support is based upon ground trajectory prediction and the AI takes into account effects on flight efficiency and ATCO workload. As soon as the flight becomes relevant to the ATCO (e.g. based on the distance or time to sector), it is displayed to the ATCO. | Tools that use 4D trajectory and SWIM data |
| | | **2040/2050:** Fully automated | |
| Plan aircraft through the sectors | TBO, FRA, MSP, AIM and MET | **2035:** Monitor aircraft through the sectors since trajectories are consistent and based on the best available MET information. ATCO handles off-nominal situations. | Prediction and advanced controller tools, holistic tools |
| | | **2040/2050:** The system/AI plans the aircraft trajectory taking into account all relevant information including weather and off-nominal situations. | |
| Assume, identify and confirm aircraft | Flight-centric ATC, CNS, TBO | **2035:** Integration of datalink and TBO allowing the automatic identification and assuming of the aircraft; ATCO is informed that the aircraft is assumed. | Datalink and its tools and an allocation system |
| | | **2040/2050:** Aircraft is seamlessly and automatically transferred from one unit to the next via system. | |
| Monitor aircraft's plan, request and provide information | Flight-centric ATC, AIM and MET, CNS | **2035:** Less coordination, more monitoring and greater use of datalink; ATCOs hold more generic validations. Information is provided to the pilot or to the ATCO without human intervention from the other side. | Conflict, SA and probing tools, datalink and its tools |
| | | **2040/2050:** The SWIM and advanced datalink are responsible for information sharing while the ATCO mostly monitors the situation. | |
| Issue instructions and coordinate changes in exit conditions | Flight-centric ATC, CNS, MSP | **2035:** ATCOs use an automated interface (Digital Integrated Network Management and ATC Planning - INAP), datalink and electronic coordination to coordinate over one of more downstream sectors. | Datalink and its tools |
| | | **2040/2050:** The system/AI manages the aircraft and coordinates (coordination is reduced in flight-centric ATC) while the ATCO approves the changes and monitors. Network- | |

| | | | |
|---|---|---|---|
| | | level view and goals are given higher priority when coordinating. | |
| Transfer aircraft | Flight-centric ATC, MSP, AIM and MET, CNS | **2035:** System starts the initiation of transfer, datalink usage and electronic dialogue (use of Common Flight Message Transfer Protocol - FMTP).<br>**2040/2050:** Complete automation of the process. | Datalink and its tools |

**Table 4 Procedural tasks after implementing SESAR innovations**

| Current continuous task | SESAR | Task after implementation | Tools |
|---|---|---|---|
| Conflict management | MSP, TBO, Flight-centric ATC, Traffic Complexity resolution, digital AIM and MET | **2035:** ATCO tasks will be more oriented towards managing and decision making. Routine tasks will be supported by system automation. Digitalisation enables enhanced detection and resolution algorithms which calculate multiple resolution options and provide the ATCO with proposals, based on applicable criteria, ATCO can upload them via CPDLC. Early conflict resolution is done by EC or PC of the upstream sector, supported by conflict resolution tools, accomplished via RBT negotiation, coordinated via INAP. Enhanced tools facilitate improved SA and decision making.<br>**2040/2050:** The system detects the conflict in downstream sector and determines a set of constraints that are sent to the aircraft to be used to determine optimal trajectory on its own. Constraints are determined based on the appropriate network requirements. The system can explain the reasoning behind the decision and it can take part in automatic coordination with adjacent units. ATCO monitors the efficiency of the system and can override AI decisions if needed. | Automated Detection and Resolution support, Complexity Management Tools, datalink, flight-centric specific complexity and workload algorithms, allocation, visualisation, and coordination tools |

| | | | |
|---|---|---|---|
| Conformance management | CNS | **2035:** The machine automatically detects non-conformance and generates a response and provides a solution. ATCOs confirm and send the solution to the aircraft. | Cleared flight Adherence tool (CLAM), Route Adherence Monitoring (RAM) tool, monitoring aids based on enhanced trajectory data (including Aircraft Trajectory Data), aircraft derived data (including ADS-B) and adapted to new navigation specifications (e.g. Required Navigation Performance 1 - RNP 1). |
| | | **2040/2050:** System interacts directly with FMS and negotiates/corrects automatically. ATCOs and pilots receive feedback. | |
| Maximise quality of service | TBO, MSP, flight-centric ATC, MSP, CNS | **2035 onwards:** It is expected that this becomes the Network Manager's task in the future, with all the aircraft flying their ideal trajectories (TBO). The controller intervenes if asked by the system. | Automated tools for predicting complexity, flight allocation system, tools that use 4D trajectory and SWIM data |
| Assess if exit conditions are met | | **2035:** The system is fully capable to assess if the exit conditions are met and can inform both the pilot and the ATCO if that is not the case. | Advanced monitoring tool, datalink |
| | | **2040/2050:** System interacts directly with FMS and negotiates/corrects automatically. ATCOs and pilots receive feedback. | |
| Workload monitoring | Traffic complexity resolution, DAC, Flight centric ATC, MSP | **2035:** The system and/or the MSP can predict a high workload at a sector even before the controller subjectively decides that they are experiencing high workload and issue an alert to the adjacent sectors and shift manager. | Advanced tools for determining complexity and workload |
| | | **2040/2050:** The system can automatically reduce the need for coordination with adjacent sectors and negotiate rerouting the incoming traffic until the workload is reduced. | |

**Table 5 Continuous tasks after implementing SESAR innovations**

| Current reactive task | | Task after implementation | Tools |
|---|---|---|---|
| React to unsolved entry problems caused by weather avoidance/emergency | INAP, FRA, Flight-centric ATC, CNS, MSP, digital MET | **2035:** If PLC can't solve entry problem in time, executive ATCO uses Integrated Coordination tools and tactical conflict detection and resolution tools to assess the necessary measures to keep the traffic safe.<br>**2040/2050:** Automatic sector coordination, the system uses probabilistic MET models to determine necessary measures in time and relays them to the upstream sector for execution. | Flight allocation system, CPDLC, Conflict Detection and Resolution tools, Conflict Risk Display Integrated Coordination |
| Respond to safety nets alerts | AIM and MET, traffic complexity resolution, TBO, MSP | **2035:** Controller reacts to alerts given by Ground based Safety Nets. The alert is provided when separation minima may be infringed or when a potentially threatening situation to the safe conduct of the flight is developing. Enhanced algorithms for STCA are improved to ensure earlier warnings, lower rates of false and nuisance alerts. Controllers' reaction is supported by resolution tools.<br>**2040/2050:** The system will evolve so that the safety alerts that are common for today's operations (STCA, MTCD, TCT) become obsolete due to improved trajectory operations and automation of tasks. The controllers will have to respond to different kinds of safety alerts, for example, a malfunction or a disagreement between different AI-based agents. | SWIM data, Advanced Support for Conflict Detection and Resolution for ATC planning in en-route |
| Respond to received co-ordinations from adjacent sectors | INAP, CNS | **2035:** ATCO receives coordination requests from the upstream sector via INAP. Conflict detection for the proposed solution is automatically performed. ATCO confirms the coordination request unless renegotiation is needed due to conflicts or other issues.<br>**2040/2050:** The system automatically revises and responds without consulting ATCO but enables the controller to see the coordinated data. | Datalink Automated Assistance to Controller for Seamless Coordination, Transfer and Dialogue |

| | | | |
|---|---|---|---|
| Respond to received radar handover proposals | CNS, FRA, MSP | **2035 onwards:** E-coordination done automatically without ATCOs acknowledgement – automatic ATC handover. | Probing and conflict detection tools, Automated Assistance to Controller for Seamless Coordination, Transfer and Dialogue |
| Process special aircraft requests | CNS, AIM and MET | **2035:** The system processes the request and advises ATCO on the effects of fulfilling such request will have on other traffic, complexity, and efficiency. ATCO accepts or issus a counter-proposal. | Probing, SA and conflict detection tools |
| | | **2040/2050:** The system decides what to do with the request according to the current air traffic situation. | |
| Respond to aircraft reports and distress signals | CNS, AIM and MET | **2035:** More information about aircraft status (e.g. cabin pressure problem, medical, etc.) is forwarded via datalink, system acknowledgement and use of closed-loop clearances. ATCO coordinates with emergency services. | Datalink related tools |
| | | **2040/2050:** Automation of acknowledgments. SA is buit automatically for all stakeholders. Emergency services are automatically involved. | |
| Respond to Estimated Time Over (ETO) revision | DAC, Traffic Complexity Resolution, TBO | **2035:** Complete automation and integration within the TBO environment and use of ARES thanks to improved procedures and automated support to enhanced ATC operations and CDM | FMP and ATCO supporting tools |
| | | **2040/2050:** The ATCO does not need to respond since the system/AI handles all the necessary responses | |

**Table 6 Reactive tasks after implementing SESAR innovations**

## 3.13 Exploratory research

As the future brings more automation, digitalisation, and the use of AI, there is a real danger of the out-of-the-loop (OOTL) effect. Since the controller is no longer in real-time control of the system, this effect poses a threat to overall safety. However, SESAR recognised this problem and decided to address it with a few projects. AUTOPACE (Automation pace) is focused on predictions on how will automation impact human performance, while MINIMA (Mitigating negative impacts of monitoring high levels of automation) is based on human-automation interaction design concepts. AUTOPACE is specific in a way that it looks quite far into the future to help with arising problems (as far as 2050). The main solutions being offered for the problems that we are facing in the future are psychological training and tailoring it to the student needs to better prepare the ATCOs of the future for their new work environment.

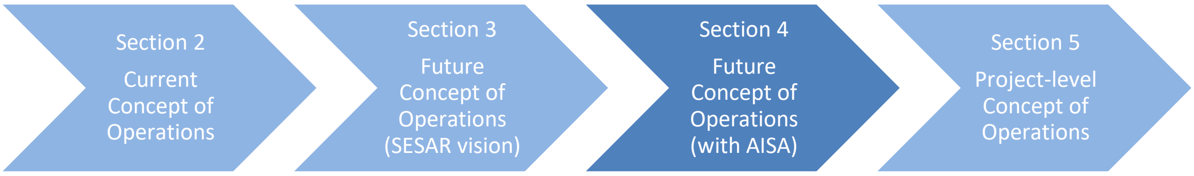
As for MINIMA, its general objective is to better understand the OOTL effect, especially in the context of future air traffic scenarios. They developed a tool that helps mitigate negative attention-related effects and named it VAC (Vigilance and Attention Controller). VAC assesses the objective vigilance data and triggers adaptive automation solutions according to its results. Regarding task allocation, several artificial and real tasks were identified as the ones that can be allocated to ATCOs to increase their participation in monitoring. Last but not least, the attention guidance support has been developed which highlights unattained aircraft to draw the operator's attention to them, thus reducing the OOTL effect [33], [34].

The ADAPT project proposes strategic models that will be able to predict the volume, flexibility and complexity of traffic demand. This will enable early flight information sharing thus allowing the identification of potential network bottlenecks. It evaluates the extent of mitigation of network congestion by assessing pre-departure and en-route flights. As the name suggests, the project aims to adapt and enable strategic planning. Cotton is a project that aims to make capacity management processes in TBOs as efficient as possible by taking advantage of the available trajectory information. It is focused on the integration of flight-centric solutions as well as demand and capacity. The three sub-objectives are as follows: improving the use of workload assessment and trajectory-based complexity, development of innovative DCB models based on DAC and flight-centric ATC solutions and finally the exploration of the integration of DAC and flight-centric ATC solutions [35].

Two ongoing projects that fall under the same category as AISA (automation & autonomy) are MAHALO (Modern ATM via Human/Automation Learning Optimisation) and TAPAS (Towards an Automated and exPlainable ATM System). MAHALO is trying to answer the question regarding automation, should it match the human behaviour or be understandable to humans. They aim to develop a special ML system that is going to try and solve ATC conflicts, as well as try to combine this with an enhanced en-route Conflict Detection and Resolution (CD&R) display. The gained knowledge will help define a framework for future AI system design. TAPAS will explore some AI-based scenarios of high automation using the eXplainable Artificial Intelligence (XAI) and Visual Analytics. This is going to bring some transparency which will then help with the implementation of AI in ATM, thus bringing us to higher levels of automation [36].

ISOBAR (Artificial Intelligence Solutions to Meteo-Based DCB Imbalances for Network Operations Planning) is a project that falls under SESARJU 51 optimised ATM network services. It aims to provide a service that is based on the AI Network Operations Plan (NOP) in a way that integrates enhanced forecasts regarding convective weather. That way it will predict imbalances in DCB and utilise AI for mitigation measures within ATFCM. ISOBAR has set four objectives for their project. First one is to reinforce ATFCM processes into local and NM roles by adding dynamic weather cells. Then they will characterise imbalances at a pre-tactical level and make user-driven mitigation plans. And lastly, they will develop a roadmap for the integration of auxiliary services into the NM platform [36].

# 4 AISA as an Enabler of the Future Concept of Operations




## 4.1 Introduction

In Sections 2 and 3 of this document, an overview of the current concept of operations and future vision based on the ATM Master Plan was given. In this section, a vision of artificial situational awareness system, working within the constraints of the SESAR vision for 2035, will be presented. Although the artificial situational awareness system will, in effect, automate ATCO's monitoring tasks, the main goal of the system is to form an additional SA system that can build up situational awareness similar to the SA of the ATCOs by using the same data that ATCO uses, making sure that every data element is considered. System is then able to reason over the collected knowledge and present its findings to the ATCO team in a transparent manner for further evaluation by the ATCOs. This will result in a widened geographic coverage and increased time span covered by awareness of the ATCO team. Since the data will be presented in a transparent way, taking into consideration all of the data provided by the automated systems, it won't cause further fatigue or out of the loop effect for the ATCO.

When considering the implementation of artificial situational awareness system in the future Concept of Operations, it is not always clear what the technological landscape will look like in 2035 or 2050. While, for example, TBO will probably be implemented to some degree, it is not known what the aircraft mix will look like in terms of equipage. Most likely, not all aircraft will fly according to TBO rules, therefore, ATCOs will still encounter a lot of situations that require their input on a tactical level. Conflict solving might even be more difficult in such scenarios, probably due to pressure to keep TBO aircraft flying according to their reference business trajectories (i.e. changing the RBT might nullify the benefits of the strategically negotiated trajectory and introduce high levels of uncertainty downstream).

In this section, first, an overview of the human-machine distributed situational awareness concept will be presented. Next, a list of technological prerequisites for implementing the AISA will be shown. These prerequisites are a link between the technologies currently planned in SESAR program and AISA. Without them, implementation of AISA would be very difficult because they represent the data exchange infrastructure which feeds data into AISA. Next topic in this section is description of the building blocks of artificial situational awareness as imagined in this project. These building blocks are knowledge graphs and reasoning engine combined with machine learning. Next, conceptual description of the system is presented. Here, general architecture of the proposed system is shown, with emphasis on individual components of the system and their interaction. Finally, tasks that could be supported by AISA are described in more detail. For each of the modes of awareness (awareness of the traffic situation, awareness of its own state, and awareness of the states of other team members), a set of tasks or potential operational improvements is shown. The section is closed with the description of the role the human will have in this novel concept of operation.

## 4.2 Distributed situational awareness

It is not only humans who can form a team with shared team situational awareness (TSA). A prerequisite for the implementation of advanced automation concepts is that artificial intelligence (AI) and human can share the SA. Exploring the effect of, and opportunities for, distributed human-machine situational awareness in en-route operations is one of the main objectives of this project.

Instead of automating isolated individual tasks, such as conflict detection or coordination, we propose building a foundation for automation by developing an intelligent situationally-aware system. Sharing the same team situational awareness (TSA) among ATCO team members and AI (Figure 9) will enable the automated system to reach the same conclusions as ATCOs when confronted with the same problem and to be able to explain the reasoning behind those conclusions. This system will at first be able to automate some of the monitoring tasks because machines cannot currently reach the same level of awareness as humans, but as the development progresses it will be able to take over more complex tasks.

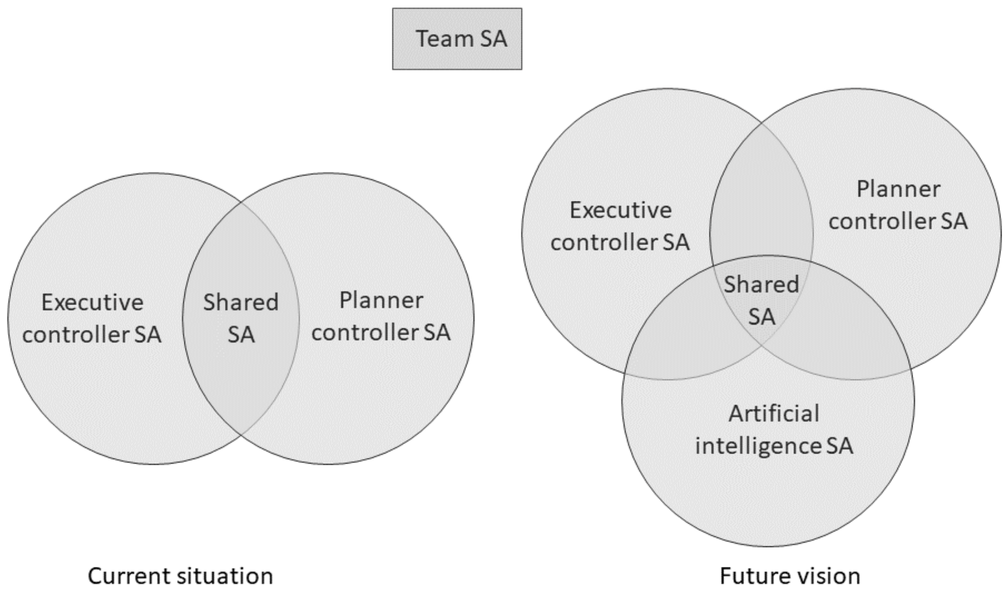



**Figure 9 Concept of Distributed Situational Awareness for Future Automated Systems**

In current ATC operations each human team member, executive or planner ATCO, is aware of the:

- traffic situation (by looking at the radar screen),
- their state (e.g. feeling rested or tired),
- other team member state (by verbal/non-verbal communication), and
- system state (by inspecting the error messages, warning lights etc).

On the other hand, in the current ATC operations, the system is unaware of the state of the ATCOs, it is unaware of the traffic situation, and it has very limited awareness of its state.

Our vision for the future automation concept of en-route ATC operations includes human-machine distributed team SA (TSA) with sector team consisting of executive ATCO, planning ATCO, and AI (actors). Actors will be able to continually monitor each-other states, with AI being aware of the probable human actors' states via analysis of traffic situation. Tasks will be allocated dynamically according to actor states, including graceful degradation of automation ensuring business continuity.

## 4.3 Prerequisites for implementing AISA

Ideas presented in this document build upon not only decades of development in the ATM domain but also on the development which is foreseen for the next 15-20 years. Thus, this concept of operations is directly dependent on some of the technologies which are currently being researched, developed, or, in some cases, already deployed. Here, a very short, non-exhaustive list of those prerequisites will be presented, based on the technologies planned in the ATM Master Plan and Section 2 of this document.

As a general framework of information management, AISA relies on successful implementation and adoption of the System-Wide Information Management (SWIM) concept. On a more specific level, AISA relies on data exchange models provided by AIXM (AIS data), FIXM (flight data), and in the future also IWXXM (weather data). Exchange models are defined in terms of data schema which can be transformed into knowledge graphs with appropriate mappers. Finally, to avoid issues of unreliable speech-to-text conversion, especially in context of VHF voice communication, and issues with natural language processing, AISA will use data-link as a primary mode of communication with the flight crews and on-board computers.

As future course of development of AISA is currently not known, it is very likely that other prerequisites will be needed.

### 4.3.1 SWIM

The objective of System-Wide Information Management (SWIM) concept is to distribute relevant information to its users in an interoperable way. This information is supposed to have good quality, be provided on time and delivered to the right place, thus facilitating net-centric ATM operations [37]. To achieve the defined objective efficiently, the following SWIM principles should be followed:

- Information provision and information consumption should be separated to the highest possible extent. Almost every participant in the ATM network is both a producer and a consumer of information.

- Each of the components in the system has, or uses, as little knowledge as applicable to other distinct components (so-called loose system coupling). This results in minimizing the barriers between systems and applications, as well as more compatible interfaces.
- Use of open standards, i.e. those that are available to the public and have different rights of use associated with them.
- Use of interoperable services that can be used flexibly within multiple systems [37].

For implementation of the AISA concept, it is necessary that the SWIM infrastructure is available to support the exchange of information via exchange models. Depending on the tasks that the artificial situational awareness should be able to perform, different levels of SWIM Technical Infrastructure (TI) profiles might be appropriate. For tasks requiring aeronautical information (e.g. aerodrome mapping data, airspace usage plans, D-NOTAMS, etc), meteorological information, network information (e.g. regulations, slots, STAMs, etc), and parts of the flight information, yellow SWIM TI profile will be appropriate[38]. For tasks which require exchanging flight information among ATC centers or between ATC centers and Network Manager in real-time and with high availability, blue SWIM TI profile will be required [38].

### 4.3.2 AIXM

The Aeronautical Information Services AIS data flows are comprised of interconnected systems and are becoming increasingly complex, as they include many suppliers and consumers of information. The global ATM is in a growing need for a cost-efficient high data quality system [39].

To keep up with the continuous introduction of automation in ATM, AIS is transitioning from paper distributed messages and products to the digital format. Aeronautical Information Exchange Model (AIXM) collects, verifies, distributes and transforms the digital aeronautical data, thus enabling the easier, seamless provision of the aeronautical information that is in the scope of Aeronautical Information Services (AIS) [39].

In AISA, AIXM is used as a source of data schema which is mapped to Resource Description Framework (RDF) schema. RDF schema is applied to validate the instance data (i.e. data pertaining to a specific situation) which is used to build the knowledge graph.

### 4.3.3 FIXM

The Flight Information Exchange Model (FIXM) is a global exchange standard that provides harmonized data structures for flight information in the scope of Flight and Flow Information for a Collaborative Environment (FF-ICE) concept. The model covers flight plan information with richer route descriptions [40]. A small part of the model is seen in Figure 10.

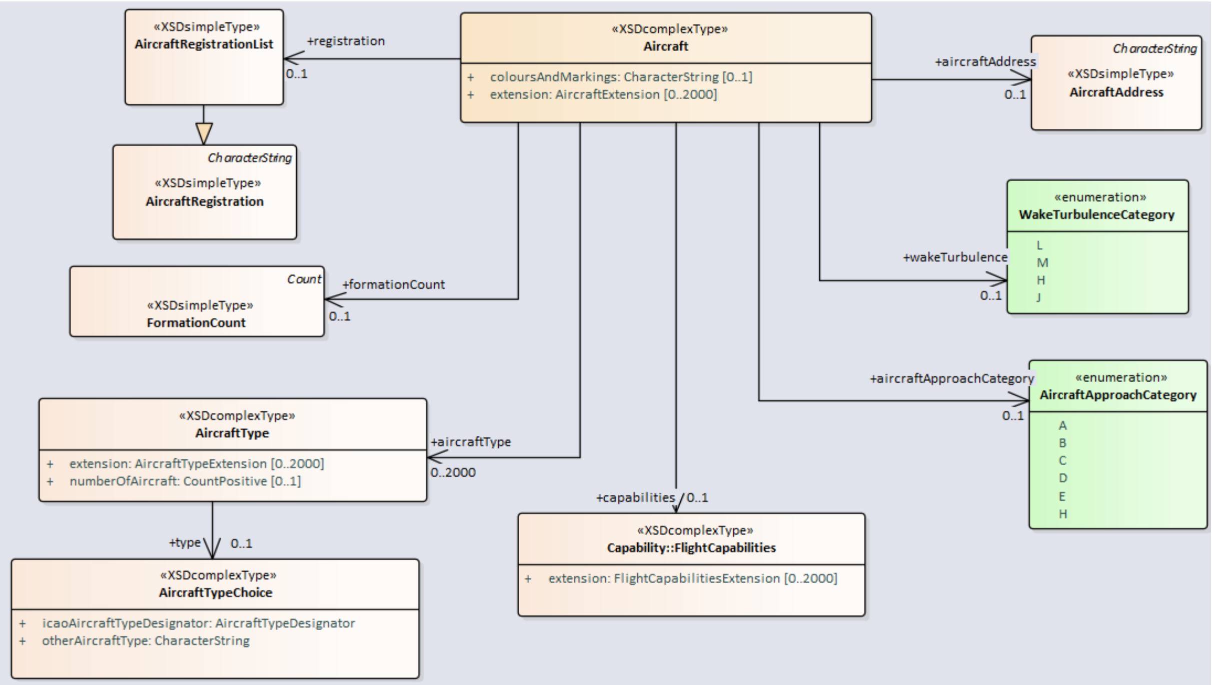



**Figure 10 Part of the FIXM Model Describing Schema for „Aircraft“ [41]**

FIXM includes the following components:

- FIXM UML model and XML schema;
- FIXM Implementation Guidance Document, which provides FIXM users with encoding rules, guidance and other instructions for implementing FIXM;
- Complementary documents (HTML documentation, data dictionary etc.) [40].

FF-ICE is a concept that defines the information requirements for flight planning, flow management and trajectory management. It's planned as the future foundation of the performance-based navigation system. It will be applied globally and support all members of the ATM community to achieve strategic, pre-tactical and tactical performance management. FF-ICE anticipates the definitions of data elements to be globally standardized and at the same time, provides the mechanisms for their exchange. The objective of FF-ICE is to establish the environment to address the current limitations of the ATM system and to enable improvements [41].

Figure 11 shows how trajectory management can be carries both strategically and tactically. On the left-hand side of the image, the operator's selected trajectory isn't available because a volume of airspace containing the trajectory is allocated to military use. The result of trajectory management is the new agreed trajectory determined before departure which goes around the airspace constraint. On the right-hand side, the military activity ended earlier than expected, but after the departure of the concerned flight. FF-ICE facilitated trajectory management includes cross-border and/or inter-state information exchange and in this case, allows the airspace user to renegotiate the trajectory to have the actual flown trajectory as close as possible to the initially chosen one [41].

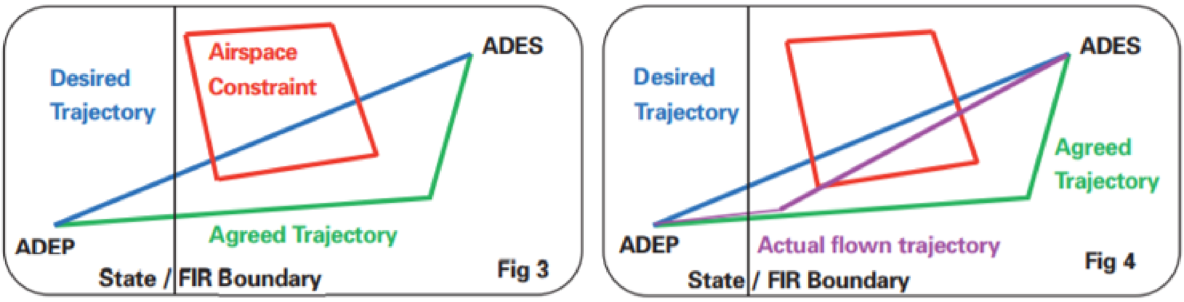



**Figure 11 FF-ICE trajectory management [41]**

Similarly to AIXM, in AISA FIXM is used as a source of data schema which is mapped to Resource Description Framework (RDF) schema regarding the flight information (as opposed to AIXM which is used to model data related to airspace and infrastructure). RDF schema is applied to validate the instance data (i.e. data pertaining to a specific situation) which is used to build the knowledge graph.

### 4.3.4 CPDLC

CPDLC is a two-way data-link system providing air-ground data communication to the ATC service. It transmits non-urgent messages to aircraft since it was made as a resort for voice communications.

The full implementation of CPDLC is expected to bring numerous benefits, such as less congestion on the ATC frequency and greater sector capacities. It has been made possible to deal with more pilot requests at the same time. Furthermore, there is a reduced probability of miscommunication due to standard messaging, which also minimizes the loss of communication.

Some of the available data link services are:

- Data Link Initiation Capability (DLIC) – it is executed before using any other data link application for the first time. It is used for enabling data link communication between an ATSU and the aircraft.
- ATC Communications Management Service (ACM) – provides the flight crew and ATCOs with automated assistance for the transfer of ATC simulations
- AT Clearances Service (ACL) – allows ATCOs and flight crews to make operational changes. Flight crews are able to send requests and reports, whereas ATCOs can issue instructions, clearances and notifications.
- ATC Microphone Check Service (AMC) – enables ATCOs to check that their communication equipment isn’t blocking the voice channel by sending an instruction to all CPDLC equipped aircraft
- Departure Clearance (DCL) – a service that provides automatic assistance for requesting and issuing departure clearances.

In AISA Concept of Operations, CPDLC is a prerequisite for those functions that require direct communication between the system and the aircraft (e.g. transfering the aircraft to the adjacent unit, requesting additional information, etc).

### 4.3.5 Building Blocks of Artificial Situational Awareness

Enabling human-machine SA requires that both entities have access to the same data. This would mean a connection must be formed between data for human use – language – and data for machine use – information. Such connection was the goal of the World Wide Web Consortium (W3C) which presented the “Semantic Web” as an extension of the World Wide Web (WWW). W3C introduced different standards such as Resource Description Framework (RDF), Web Ontology Language (OWL) and XML (Extensible Markup Language) to aid in creating and connecting data [42].

An example, featured on Wikipedia, does a good job of explaining the concept – the text “Paul Schuster was born in Dresden” is featured on a website, but by using the proposed rules it can also be used by machines to form a graph. A type named “Person” is created, which has the properties “Name” and “BirthPlace”. The first property has a value of “Paul Schuster”, and the second value of “Dresden”. This creates a (semantic) triple – three elements connected in a subject-predicate-object – which are then visualized as two nodes connected by an edge [42].

Implementation of such system would enable a machine to read and connect data in largely the same way a human does. By building the framework as an extension of WWW, the Internet itself is used as a repository of knowledge. As we will see, incorporating the proposed standards enables data acquisition from other sources.

In recent times, several other concepts have emerged that implement these ideas, but having been created by different entities they are not consistently labelled and defined. There is no consensus on the proper nomenclature of these systems, thus leading to a plethora of supposedly equivalent (but in reality quite different) systems. If we adopt the naming proposed in the paper “Towards a Definition of Knowledge Graphs”, we can distinguish between knowledge bases, knowledge-based systems and knowledge graphs [43].

Knowledge bases are thus collections of organized data, improving and exceeding the capabilities of a database. Knowledge-based systems include knowledge bases, but add a reasoning engine which can derive new knowledge from the collected data. A knowledge graph offers an improvement to knowledge-based systems by adding integration capabilities – the collection and integration of data from external sources.

Choosing to follow this nomenclature leads us to believe that AISA will need a knowledge graph capable of collecting and integrating data into a knowledge base already populated by ATM rules (Table 7). KG used in AISA will be automatically populated by aeronautical data provided in AIXM and FIXM. This data is already available in structured formats complying to a strictly specified schema which enables drawing the semantic relationships between data. However, ATC-specific rules, which are not encoded in the aeronautical data, need to be included before the system can provide reasoning capabilities. The reasoning engine would then be able to derive new knowledge and determine logical consequences from available data.

| AISA Knowledge and Information Sources | ATCO Knowledge and Information Sources |
|---|---|
| **Static information** (from AIXM, …) | the map on the radar screen with info about airports, navaids, etc. |
| **Situation-specific observations** (weather, aircraft positions) | radar screen with current positions of aircraft and additional aircraft info, etc. |
| **Predictions** (from ML modules) | augmented radar screen with predicted trajectories + alerts |
| Logically **derived Information** (from rule-based reasoning) | Implicit or explicit thoughts/judgments in the ATCO's mind/memory |
| ATCO's actions (**activity log** of human-machine interactions) | ATCO's self-observation, and observation of colleagues |
| **The provenance** of 1. – 5. | ATCO's knowledge about equipment + ATCO's reflective thinking |

**Table 7 Knowledge represented in the AISA Knowledge Graph**

At this point, a definition of a reasoning engine is in order. Also known as a rules engine, semantic reasoner or just reasoner, it is a piece of software that is meant to infer logical consequences from a set of facts. Although the two terms are sometimes synonymous, reasoning engine is a more general term than inference engine.

A reasoning engine usually works by applying either *forward chaining* or *backward chaining* to the data. The two methods present a mirror approach to data – forward chaining starts with the available data and "reasons" its way to an answer, while backward chaining starts with the answer and tries to prove that it's correct by searching through available data. For these reasons, they are sometimes called "data-driven" and "goal-driven" methods, respectively. Reasoning engine in AISA will be used to implement those rules that cannot be described via the KG. This will expand the capability of the system to implement complex rules and produce queries based on them.

## 4.4 Conceptual Description of the System

In this section, a description of the proposed system will be presented. It is not a system that will be built during this project but a vision of the future possible system if this project proves its feasibility and the development continues.

At the core of the concept are controllers, Figure 12. Whether the ATCO team is made of conventional Executive/Planner couple or some other future combination of roles (e.g. in case of a multi-sector planner), they will be joined by AI. As usual, ATCOs work at their Controller Working Position (CWP) which they use to gather information, build their SA, make decisions, and implement actions.

CWP is used to present aeronautical data to the ATCO (airspace data, aircraft positions, etc.). Even though it is highly pre-processed, in terms of decision-making this data can be considered as 'raw' data. Aeronautical data is also fed into the AISA and other tools that need it. In this diagram, machine learning modules are of special interest because one of the functions of AISA will be to check the plausibility of their results.

Both AISA and ML modules can work as automation tools by supporting ATCO decision-making (2035 vision) or performing tasks under ATCO's supervision (2040/2050 vision). However, automating ATCO tasks is only one of the functions of AISA and a lesser one at that. AISA will primarily be the central decision-support tool with the awareness of all the relevant interactions enabling it to suggest or choose the correct course of action.

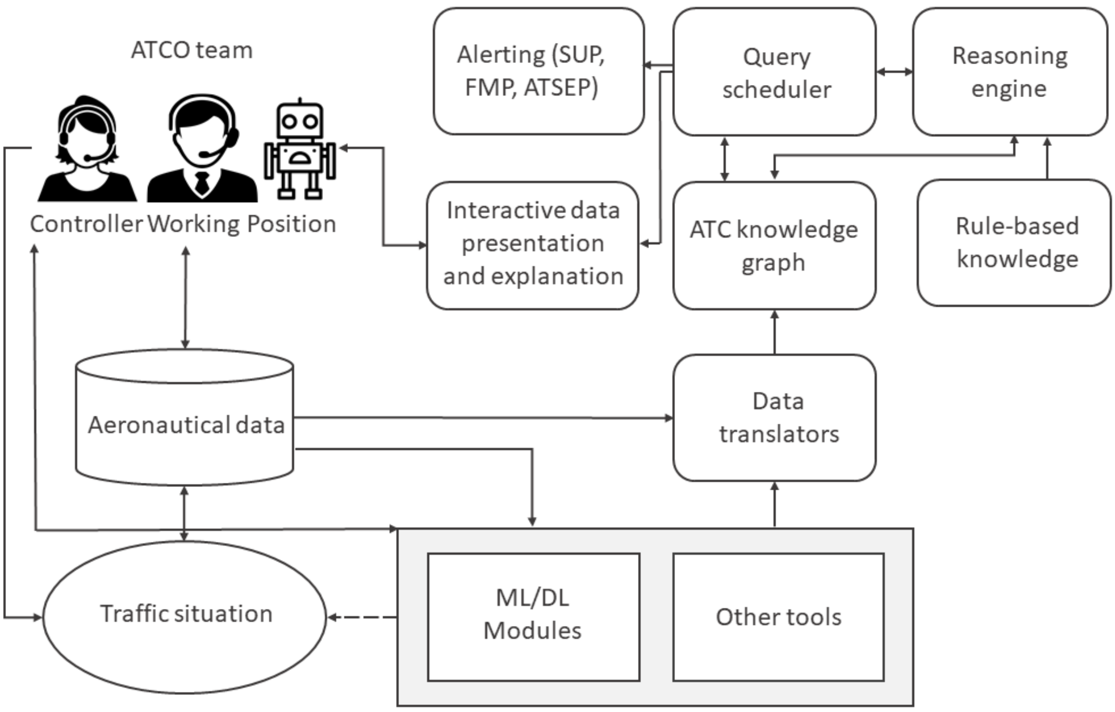



**Figure 12 Conceptual diagram of the System**

At the core of the system is a knowledge graph system containing factual knowledge organized in a set of named graphs. The knowledge graph is populated by transforming the aeronautical data conforming to the exchange models (AIXM, FIXM, etc.). In addition to factual knowledge in a knowledge graph, a knowledge-based system needs to manage and execute rule-based knowledge. Rule-based knowledge is defined and executed on top of the factual knowledge in the knowledge graph. There are many different rule-based formalisms, many rooted in Datalog, all coming with their advantages and limitations. In AISA a key requirement is to have a flexible approach to rule-based reasoning, to be able to fulfil also unforeseen requirements which will emerge during the project. Prolog, more exactly, the versatile and tried and tested SWI-Prolog system, facilitates such a flexible approach. SWI-Prolog aims at scalability by supporting multi-threading which can efficiently exploit multi-core hardware. It is also well adapted for application development because it supports many interfaces to other IT components such as document types, network protocols, and low-level interfaces with C, C++, C#, Python, and Java.

Machine learning (including deep learning – DL) will be used at a lower level to predict individual probabilistic events whereas reasoning engine is used at a higher level to draw conclusions from the system state. By combining reasoning engine with ML, we believe that it will be possible for AI to be 'aware' of the situation in a manner similar to a human, that is, AI will be able to assess complex interactions between objects, draw conclusions, explain the reasoning behind those conclusions, and predict future system states.

Queries will be developed, in cooperation with ATCO experts, for each of the tasks that the system should be able to execute. By running these queries in short intervals, a continuous monitoring will be achieved. Running queries over large stores of triples can be time consuming, therefore optimization techniques will be employed to reduce the number of triples and hardware will be adapted for the purpose (large memory and multiple cores). Queries will be used to achieve the situational awareness and provide results to the ATCO via CWP. Also, results from queries related to system state, i.e. detecting the performance degradation, can be forwarded to air traffic safety electronics personnel (ATSEP), and results from queries related to workload or demand-capacity balancing in general, can be sent to shift supervisors (SUP) or flow management position (FMP).

The future ConOps envisioned in this project is based on the ability of an autonomous system to reach the awareness level at which the system is a predictive subject, it is history-sensitive and self-aware, containing a decision-making process involving a simulation engine, that can simulate the effects of actions on the environment and on the subject, therefore predicting future states and behaviours of the subject and its environment. In addition to self-awareness, such system possesses group awareness meaning that the subject distinguishes between itself, the environment and the peer group. The peer group is treated differently by associating it with peer group-specific expectations and goals. It is expected that the research activities conducted in this project will show that such system is possible in a very specific environment such as en-route air traffic control operations, however, reaching higher levels of awareness will be possible only after further long-term development.

## 4.5 Tasks Supported by Artificial Situational Awareness System

As mentioned previously, in this project all relevant facts and rules will be encoded in a knowledge graph and as predicates, respectively. Reasoning can be done by automatic inference, which is a process for filling in the gaps in the knowledge graph, or by running a query which looks to answer a specific question. Queries will be developed, in cooperation with ATCO experts, for each of the tasks that are to be automated. By running these queries in short intervals, continuous monitoring will be achieved. Running queries over large stores of triples can be time-consuming, therefore optimization techniques will be employed to reduce the number of triples and hardware will be adapted for the purpose (large memory and multiple cores). Queries will be used to achieve situational awareness. As explained in previous sections the system will be aware of:

- the traffic situation,

- its own (system's) state, and
- other team member's states.

### 4.5.1 Awareness of Traffic Situation

To be aware of the traffic situation, in terms of artificial situational awareness, means that the system is able to gather all necessary data regarding the current traffic situation, turn it into knowledge, and then draw conclusions based on the knowledge gained. Benefits of the system being aware of the traffic situation are predicted to be numerous, especially in the 2050 time-frame, however, the most important benefits currently envisioned are: automation of monitoring tasks, central coordination of tools/modules, automation of gathering missing information, and automated reporting (Figure 13).

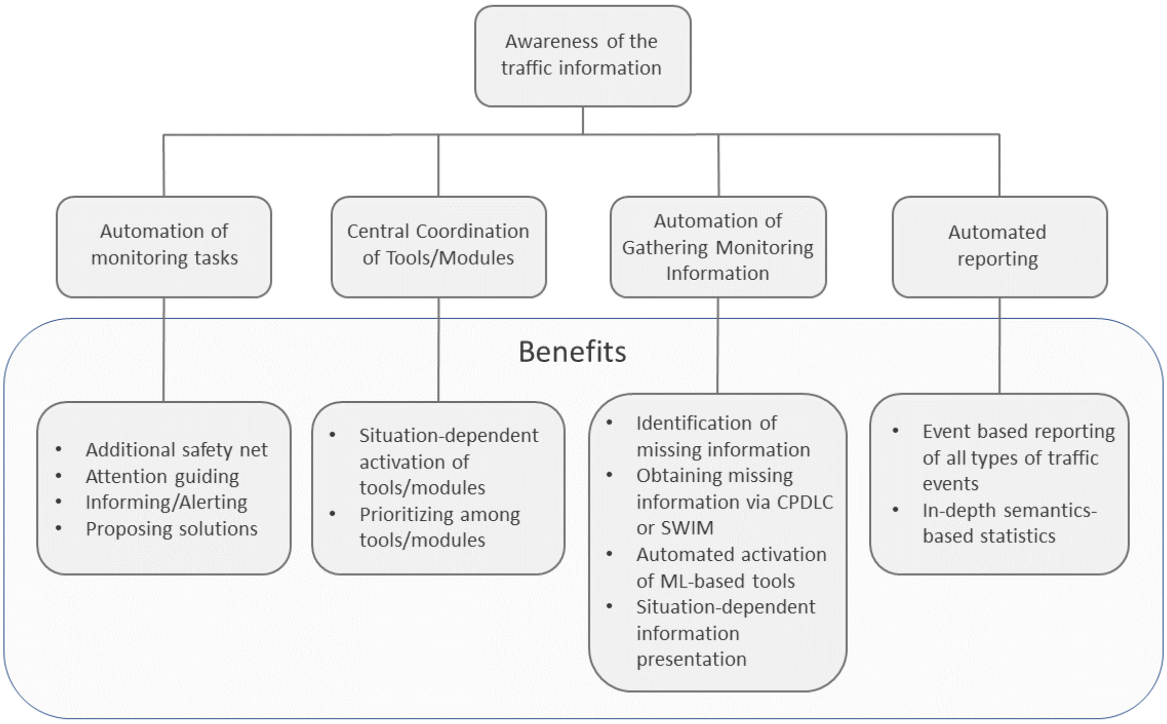



**Figure 13 Predicted Benefits of the System Being Aware of the Traffic Situation**

#### 4.5.1.1 Automation of the Monitoring Tasks

Though the automation of ATCO tasks is not the primary goal of AISA, there is an overlap here with the tasks that en-route ATCOs routinely perform. Artificial situational awareness, though probably for the foreseeable future not as insightful as human, is more meticulous and it never turns off nor switches to other things.

In previous sections, Tables 1-3 were used to show the list of current ATCO en-route tasks and Tables 4-6 showed the changes to those tasks that are expected to occur based on the planned implementation of SESAR innovations. In this section, an overview of possible ways that AISA could be used on a task level is presented.

For ATCOs, each of these tasks is usually just part of the bigger process of decision-making. Similarly, artificial situational awareness system can be designed to perform actions upon detecting a certain set of conditions. Ability to perform these actions is the property that makes such a system useful. Therefore, for each of the tasks mentioned previously, possible future role of AISA is visible in the following tables.

| Current procedural tasks | Description of Future Tasks | Possible Future Role of AISA |
|---|---|---|
| Detect planned flight | **2035:** Flight is continuously being tracked by the system. Flight's trajectory is being updated and shared with all stakeholders as soon as any change is made. Automated detection support is based upon ground trajectory prediction and the AI takes into account effects on flight efficiency and ATCO workload. As soon as the flight becomes relevant to the ATCO (e.g. based on the distance or time to sector), it is displayed to the ATCO. | AISA could integrate knowledge from all sources and decide when to display individual flights based on the relevance to the ATCO. In advanced concepts, such as flight-centric ATC, continuous selection of only relevant information to be displayed to the ATCO could be performed. |
| | **2040/2050:** Fully automated | |
| Plan aircraft through the sectors | **2035:** Monitor aircraft through the sectors since trajectories are consistent and based on the best available MET information. ATCO handles off-nominal situations. | For each planned trajectory, AISA could initiate analysis of interactions with other flights and determine the possible effects on complexity, workload, and efficiency. Though KG will not be able to make predictions, it could integrate knowledge from other modules, such as ML/DL modules, to predict future trajectory of the aircraft and assess the traffic situation in advance. Furthermore, AISA will be able to detect if the predicted trajectories are feasible based on other available information (e.g. aircraft performance, winds, convective weather, etc). |
| | **2040/2050:** The system/AI plans the aircraft trajectory taking into account all relevant information including weather and off-nominal situations. | |
| Assume, identify and confirm aircraft | **2035:** Integration of datalink and TBO allowing the automatic identification and assuming of the aircraft; ATCO is informed that the aircraft is assumed. | AISA coould determine the appropriate moment to assume incoming flights based on predefined rules. It could use CPDLC to automatically request additional information if needed. |
| | **2040/2050:** Aircraft is seamlessly and automatically transferred from one unit to the next via system. | |
| Monitor aircraft's plan, request and | **2035:** Less coordination, more monitoring and greater use of datalink; ATCOs hold more generic validations. Information is provided to the pilot or | AISA could automatically answer pilot's requests for additional information. It could request |

| | | |
|---|---|---|
| provide information | to the ATCO without human intervention from the other side.<br>**2040/2050:** The SWIM and advanced datalink are responsible for information sharing while the ATCO mostly monitors the situation. | additional information and integrate it with the rest of the knowledge to better inform the decision-making process. |
| Issue instructions and coordinate changes in exit conditions | **2035:** ATCOs use an automated interface (Digital Integrated Network Management and ATC Planning - INAP), datalink and electronic coordination to coordinate over one of more downstream sectors.<br>**2040/2050:** The system/AI manages the aircraft and coordinates (coordination is reduced in flight-centric ATC) while the ATCO approves the changes and monitors. Network-level view and goals are given higher priority when coordinating. | AISA could automatically detect events that should trigger changes in exit conditions and autonomously initiate coordination process. |
| Transfer aircraft | **2035:** System starts the initiation of transfer, datalink usage and electronic dialogue (use of Common Flight Message Transfer Protocol - FMTP).<br>**2040/2050:** Complete automation of the process. | AISA could transfer flights as soon as the required conditions are met. |

**Table 8 Procedural tasks**

| Current continuous task | Description of Future Tasks | Possible Future Role of AISA |
|---|---|---|
| Conflict management | **2035:** ATCO tasks will be more oriented towards managing and decision making. Routine tasks will be supported by system automation. Digitalisation enables enhanced detection and resolution algorithms which calculate multiple resolution options and provide the ATCO with proposals, based on applicable criteria, ATCO can upload them via CPDLC. Early conflict resolution is done by EC or PC of the upstream sector, supported by conflict resolution tools, accomplished via RBT negotiation, coordinated via INAP. Enhanced tools facilitate improved SA and decision making. | AISA could autonomously initiate conflict detection tools in regular intervals to assess the situation and probability of conflict. It can then use that knowledge to determine whether to initiate conflict resolution. It could guide the attention of the ATCO towards those conflicts that are a priority or to those that are most complex (based on the advanced complexity assessment tools). Furthermore, it could keep track of conflict detection |

| | | |
|---|---|---|
| | **2040/2050:** The system detects the conflict in downstream sector and determines a set of constraints that are sent to the aircraft to be used to determine optimal trajectory on its own. Constraints are determined based on the appropriate network requirements. The system can explain the reasoning behind the decision and it can take part in automatic coordination with adjacent units. ATCO monitors the efficiency of the system and can override AI decisions if needed. | tools performance in order to help determine whether the system operates nominally. |
| Conformance management | **2035:** The machine automatically detects non-conformance and generates a response and provides a solution. ATCOs confirm and send the solution to the aircraft.<br>**2040/2050:** System interacts directly with FMS and negotiates/corrects automatically. ATCOs and pilots receive feedback. | AISA could autonomously monitor conformance both in space and in time. Also, upon detecting non-conformance it could keep track of the deviations, inform the ATCO, guide ATCOs attention to possible consequences of non-conformance, and notify the pilot. |
| Maximise quality of service | **2035 onwards:** It is expected that this becomes the Network Manager's task in the future, with all the aircraft flying their ideal trajectories (TBO). The controller intervenes if asked by the system. | While quality of service will probably be handled on strategic level, AISA could be useful in off-nominal situations. For example, it could detect possible equipment degradation and inform the supervisor or NM directly to start demand-capacity balancing. |
| Assess if exit conditions are met | **2035:** The system is fully capable to assess if the exit conditions are met and can inform both the pilot and the ATCO if that is not the case.<br>**2040/2050:** System interacts directly with FMS and negotiates/corrects automatically. ATCOs and pilots receive feedback. | AISA could assess if the exit conditions are met by querying the knowledge graph. It could then determine which action is necessary if conditions are not met. |
| Workload monitoring | **2035:** The system and/or the MSP can predict a high workload at a sector even before the controller subjectively decides that they are experiencing high workload and issue an alert to the adjacent sectors and shift manager.<br>**2040/2050:** The system can automatically reduce the need for coordination with adjacent sectors and negotiate rerouting the incoming traffic until the workload is reduced. | AISA could monitor workload by assessing the number of aircraft-aircraft interactions that the ATCO needs to take into consideration. Another approach could be to assess the number of tasks that the ATCO needs to perform. |

**Table 9 Continuous tasks**

| Current reactive task | Description of Future Tasks | Possible Future Role of AISA |
|---|---|---|
| React to unsolved entry problems caused by weather avoidance/emergency | **2035:** If PLC can't solve entry problem in time, executive ATCO uses Integrated Coordination tools and tactical conflict detection and resolution tools to assess the necessary measures to keep the traffic safe.<br>**2040/2050:** Automatic sector coordination, the system uses probabilistic MET models to determine necessary measures in time and relays them to the upstream sector for execution. | This task is most likely best left to humans. However, AISA could keep track of unsolved entry (and other) issues and guide ATCO's attention to them. |
| Respond to safety nets alerts | **2035:** Controller reacts to alerts given by Ground based Safety Nets. The alert is provided when separation minima may be infringed or when a potentially threatening situation to the safe conduct of the flight is developing. Enhanced algorithms for STCA are improved to ensure earlier warnings, lower rates of false and nuisance alerts. Controllers' reaction is supported by resolution tools.<br>**2040/2050:** The system will evolve so that the safety alerts that are common for today's operations (STCA, MTCD, TCT) become obsolete due to improved trajectory operations and automation of tasks. The controllers will have to respond to different kinds of safety alerts, for example, a malfunction or a disagreement between different AI-based agents. | AISA could keep track of the performance of safety nets or other AI modules and raise the alert towards the ATSEP personnel in order to keep them in the loop regarding the off-nominal operation of the system. |
| Respond to received co-ordinations from adjacent sectors | **2035:** ATCO receives coordination requests from the upstream sector via INAP. Conflict detection for the proposed solution is automatically performed. ATCO confirms the coordination request unless renegotiation is needed due to conflicts or other issues.<br>**2040/2050:** The system automatically revises and responds without consulting ATCO but enables the controller to see the coordinated data. | AISA could check if the coordination request induces new conflicts or other issues. It could present the results of the analysis directly to the ATCO with explanation of the expected effects. |
| Respond to received radar handover proposals | **2035 onwards:** E-coordination done automatically without ATCOs acknowledgement – automatic ATC handover. | ASIA keeps track of the handover process. |
| Process special aircraft requests | **2035:** The system processes the request and advises ATCO on the effects of fulfilling such request will have on other traffic, complexity, and efficiency. ATCO accepts or issus a counter-proposal.<br>**2040/2050:** The system decides what to do with the request according to the current air traffic situation. | AISA could check if the special request induces new conflicts or other issues. It could present the results of the analysis directly to the ATCO with explanation of the expected effects. |

| | | |
|---|---|---|
| Respond to aircraft reports and distress signals | **2035:** More information about aircraft status (e.g. cabin pressure problem, medical, etc.) is forwarded via datalink, system acknowledgement and use of closed-loop clearances. ATCO coordinates with emergency services. | AISA could autonomously alert emergency services if certain conditions are met. It could help coordinate with other units by sending relevant information directly to them. It could help keep SA for all new services coming on-board during the emergency. |
| | **2040/2050:** Automation of acknowledgments. SA is buit automatically for all stakeholders. Emergency services are automatically involved. | |
| Respond to Estimated Time Over (ETO) revision | **2035:** Complete automation and integration within the TBO environment and use of ARES thanks to improved procedures and automated support to enhanced ATC operations and CDM | This task will be handled via conformance monitoring system. |
| | **2040/2050:** The ATCO does not need to respond since the system/AI handles all the necessary responses | |

**Table 10 Reactive tasks**

The current approach to automating these tasks is to hard-code specific functionality into the system (e.g. conformance monitoring), however, with AISA it will be possible to almost infinitely **scale the number of different conditions that can be detected by adding new nodes to the knowledge graph or writing new queries** that can extract required conclusion based on the existing knowledge. Adding new actions, especially those where the system intervenes automatically, will remain a more difficult problem.

#### 4.5.1.2 Central Coordination of Tools/Modules

Current AI systems do not exhibit traits of the general intelligence i.e. they are not adaptable to different environments and problems as humans. In contrast with the general intelligence, narrow, or sometimes also called weak, artificial intelligence is best suited for a specific task. This means that a system built for one purpose, e.g. playing chess, will not be able to fulfil a different purpose, it will not fare well in a game of Go. In the current state-of-the-art of AI development, a path to artificial general intelligence (AGI) is not clear. Therefore, in our vision of Concept of Operations for 2035/2050, AGI will be disregarded. Another reason to disregard AGI is because if the opposite is true, if it indeed becomes possible, the disruption caused by it are tremendously difficult to predict.

When putting AGI aside, what remains is the current paradigm of increasingly elaborate and better performing AI tools which still only solve individual tasks. Proliferation of such tools is bound to spill over into the ACCs and many such tools are most likely already being developed. With increased number of tools, it is likely that even activation of the right tool at the appropriate time might become cumbersome for the ATCO. Managing all those tools, feeding correct information to them, activating them at the appropriate time for the appropriate traffic situation, and choosing the time to display the results is where situationally aware system could be of assistance. AISA will thus operate as a hybrid AI system, with individual tools using ML or other methods and the main system using the KG and first-order logic to perform the decision-making.

Furthermore, for safety-of-life purposes it is a common practice to have multiple tools or systems performing the same task and the correctness of the result is guaranteed if all tools come to the same result. For example, modern aircraft use 3 or 4 inertial navigation systems simultaneously to determine, by consensus, if the navigation solution is correct. As soon as one of the systems diverges, it becomes flagged as unserviceable. Similarly, in the ACC operations room, a central decision-making system will probably be necessary to arbitrate among different tools providing the same service. Obviously, such system can be hard-coded, however, KG-based solution is much more flexible and it can integrate the decisions it makes with other knowledge to improve the situational awareness. The need for such coordination system is further increased due to the fact that redundant safety-of-life systems usually need to be made by different vendors to ensure that the same error will not occur in all of the systems.

#### 4.5.1.3 Automation of Gathering of the Missing Information

Some information might not be available all the time or it might be available only on demand. In current operations, ATCOs often need to ask flight crews or adjacent sector's ATCOs for additional information before making a decision (e.g. asking aircraft to share their current heading). This is a routine but time-consuming task. KG-based systems, as in the one envisioned in this project, can be aware of the knowledge that is needed to make a decision and they can, consequently, identify which information or knowledge is missing. By associating a certain type of information with a specific data originator, it can be determined from where that information should be sought. If the system can use communications independently, it can ask the information originators for the necessary information without distracting the ATCO (e.g. CPDLC could be used to obtain information from the aircraft; SWIM could be used to obtain information from other stakeholders). By filling in the gaps in the KG, the system will be more aware of the situation and it will have prepared all needed information for the ATCO if they decide to use it at some point.

On the other hand, some information or knowledge might be missing but the originator of that data is the system itself or tools attached to it. For example, an estimate of the time overhead a certain point might be needed to decide when to start the descent. If the system has an ML-based tool which determines that time, it will be necessary to activate it for this specific flight. Therefore, the KG-based system will also be aware of the tools at its disposal and their function in terms of filling in the gaps in the KG.

Another use of AISA is to filter only relevant information needed to make a decision. Such filtering could be provided for a given traffic problem, e.g. a conflict, for which the system can show only those flights which are relevant for solving that specific problem. By using the semantic information, the system can decide which information is relevant, i.e. logically connected with the source of the problem and possible solutions. Thus, ATCOs attention could be guided to the most relevant information. Such situation-dependent information presentation can also be used for a more subtle filtering, e.g. showing only that weather phenomena that are actually making an impact on traffic flows. The goal of situation-dependent information presentation is to avoid overwhelming the ATCO with the unnecessary information, however, a balance has to be struck between showing too much information and causing an OOTL effect.

#### 4.5.1.4 Automated Reporting

Current ATM systems log a lot of data, however, automated reporting is used in only a handful of cases. For example, an STCA activation will usually be logged and reported to the shift supervisor. This is an example of the relatively simple logic: *alert activates → report to supervisor*. With the KG-based system, for each event that has to be reported a query can be defined which will provide the necessary information. Each query can be based on any of the knowledge contained in the KG. Therefore, a report can be made for an arbitrary set of conditions. The list of these queries can be expanded as much as needed, based on the operational requirements, without changing the source code of the system and requiring the validation of the changes.

Furthermore, by logging the results of the relevant queries over time, a more informative set of statistics can be provided.

### 4.5.2 Awareness of the System State

Queries related to self-monitoring will be used to make sure that the system is operating nominally. These will allow AI to be aware that part, or whole, of the system is failing and to transfer the tasks back to the ATCOs. Failure is possible for many reasons, such as failure to receive required data, failure of other equipment, failure to infer a conclusion in a reasonable time, etc. By querying the state of itself, the system will be able to degrade gracefully and communicate the fact to the rest of the team, while also providing troubleshooting information in the form of a broken reasoning chain.

As artificial situational awareness system is meant to be a central decision-making tool for automation, it will also be necessary for it to be able to detect faulty modules which are attached to it. Knowledge graph by itself is not quite suitable for making predictions in the presence of the uncertainty. As mentioned previously, for those tasks, machine learning (ML) approach is more useful. In theory, combining KG with ML yields a system that is both capable of reasoning and prediction/estimation. The issue with ML is the lack of transparency in some of the methods. Neural networks are infamously opaque in their operation which is unacceptable for safety-of-life systems. Small changes on the input side can result in major changes on the output side (e.g. an image of a panda being classified as gibbon after making imperceptible changes to the original image [44]). To reduce the probability of such errors occurring during the operation of the ML modules in AISA, a method for checking the plausibility of ML predictions will have to be developed. Checks can be made at both the input and the output side of the ML module by forming appropriate queries.

These queries will monitor inputs into, and solutions provided by machine learning modules. Inputs will be checked to determine whether they are within operating parameters of the ML modules (e.g. check if the inputs are something that neural network was trained to use as inputs). If they are not, the AISA will consider results of the ML algorithm unreliable and, if necessary, alert the ATCO (i.e. 'known unknowns'). Results will be queried to determine if they are reasonable compared to the facts stored in the knowledge base (e.g. unreasonably high or low predicted speeds, altitudes etc.) and if they are not, alert the ATCO, search for alternative solutions, or just discard the results.

In addition, AISA can be used to keep track of the accuracy of ML predictions or estimates. Each prediction can be stored in the KG, tagged with the time at which the prediction was made and the time for which the prediction was made. Upon reaching the time for which the prediction was made, an assessment of accuracy can be performed and stored. This enables real-time tracking and alerting in case a system degradation occurs.

### 4.5.3 Awareness of Team Member's State

When working in a team, humans instinctually assess each other's state. An ATCO can notice without much effort whether a team member is fatigued or well-rested. Shift supervisors routinely assess ATCO's workload not only by looking at aircraft counts but also by noticing signs of fatigue in person. For machines to be able to join the team situational awareness, they need to be able to assess the team member's state as well.

Monitoring the ATCO's stress level, for instance, can be achieved through various means such as monitoring the heart-rate, perspiration, temperature, or blood pressure. However, without fitting the ATCOs with distracting and invasive hardware, there are not that many ways to assess their stress or workload.

Workload, however, can be inferred based on the traffic complexity with the idea that the more complex the traffic is, the more interactions there will be for the ATCO to solve, the higher the workload will be. Now, this can be estimated by ML systems trained for complexity assessment. This approach will be taken in AISA, with a dedicated ML module used to assess the complexity of the current air traffic situation. Furthermore, another indirect way of measuring the ATCO workload is by keeping track of all the tasks that the ATCO had to perform. None of these methods will be exact, but they can give the system low-level awareness of the team member's state.

The purpose of this type of awareness can be, in advanced systems, to alert the shift supervisor or flow manager that there is a need to employ some form of demand capacity balancing measures.

## 4.6 Additional Benefits of the Artificial Situational Awareness

Artificial situational awareness will enable the system to possess reasoning capabilities which are explainable, completely transparent and generalizable. Whereas machine learning systems, such as deep neural networks, effectively work as black boxes, reasoning engine can explain all the results it provides. Also, it can be used to check results obtained from ML systems for logical inconsistency or implausibility in a similar way that the human can determine when those results are faulty. Furthermore, when plugging in several ML modules doing the same type of estimation or prediction in different ways (even produced by different vendors), artificial situational awareness can be used to arbitrate which of the machine learning modules is correct.

Artificial situational awareness system will thus increase safety by introducing what is in effect an additional safety net. In effect, it will serve as an always observing team member whom can be relied on to perform tedious monitoring tasks with high reliability.

It will improve interoperability between different systems by improving data handling which comes as a by-product of using knowledge graphs for data management. It will also increase sector capacity by automating some of the monitoring tasks and enabling the introduction of other automation systems.

## 4.7 The Role of Human

There are adverse effects of automating those tasks which are usually performed by humans. Automating the ATCO's tasks leads to de-skilling i.e. ATCOs lose the ability to perform certain tasks if they don't perform them regularly. However, one goal of automation, among others, is to increase the capacity. In theory, human and machine (automation) together should have greater capacity than the human alone. In nominal conditions this is not a problem, however, if automation fails the human alone needs to be able to handle the traffic situation, now with the increased number of aircraft. If the human could handle that level of traffic alone, the automation would not have been necessary in the first place. This is now the well-known paradox of task automation in ATC.

This issue has already been seen in other areas of aviation, mainly with pilots experiencing skill degradation due to reliance on the autopilot. Other issues are complacency and out-of-the-loop effect, with pilots having great difficulty forming situational awareness during system failure (e.g. Air France Flight 447). Improved training and better equipment are often touted as possible solutions in the aftermath of such accidents.

In AISA, the vision of the future operations includes humans in the central role. The system should monitor the traffic and help guide the ATCO's attention towards those tasks that are best suited to humans such as decision-making. Also, humans must be ready to handle the unexpected situations, such as those tasks where automation cannot adapt. However, the question remains how can ATCO take over all those monitoring tasks if AISA fails. Increased workload would be, by definition above, inherently impossible to handle by a human alone. In those cases when the AISA fails partially, or it detects failure of a specific automated tool, we can consider different avenues for graceful degradation of the system, greatly helped by the system's situational awareness (including awareness of its own operation). On the other hand, if the failure is complete, we can expect the ATCO's workload to increase dramatically and safety to reduce substantially. One parallel to that situation is a complete radar failure in radar ATC during which ATCOs need to switch to procedural ATC. Situations like these are extremely difficult for ATCOs but fortunately also very rare. The obvious solution is to have resilient and adaptable systems where partial degradation is possible but complete failure extremely unlikely. Working in that environment means that the **ATCO will need to take over part of the tasks for some time but never all the tasks all the time**. We believe that to build resilient systems it is necessary to build situationally-aware systems.

The AISA system can be adapted to various circumstances but those changes are probably not going to happen on-line. Improvements in monitoring or alerting will most likely be implemented by periodically expanding the knowledge graph or by adding new queries. If the improvement introduces new actions performed autonomously, it will be a much more thorough validation in line with similar processes today. Therefore, even in the 2040/2050 vision, ATCOs will be crucial.

When dealing with the unforeseen circumstances, humans have at least two major advantages over AI:

- they are extremely adaptable (AISA will not be able to adapt in real-time, new knowledge will have to be inserted into the knowledge graph); and
- they use powerful heuristics (decision-making short-cuts which help us provide imperfect solutions very quickly instead of tediously calculating the best possible solution).

This will especially be needed when equipment degradation occurs. It is not difficult to imagine a situation in which an automated tool fails. In that case, ATCO will have to be able to take over and perform that task manually. If any tool can fail, then ATCO needs to be able to do that task manually. Therefore, it is most likely that the ATCO will have to be able to perform almost all current tasks if so required, but never all of them at once. This is why ATCO training will need to be expanded in the future to include training those skills which are not being used enough during the routine operations.

## 4.8 Conclusion

The fourth section has presented a vision of artificial situational awareness system that can build up situational awareness similar to the ATCOs SA. In such system artificial intelligence (AI) and human can share the SA, which is then called team situational awareness (TSA). Sharing the same TSA among ATCO team members and AI will enable the automated system to reach the same conclusions as ATCOs when confronted with the same problem and to be able to explain the reasoning behind those conclusions. This will lead to widening geographical coverage and increased time span covered by awareness of the ATCO team. However, ATCOs will still encounter a lot of situations that require their input on a tactical level and conflict solving might be even more difficult in such scenarios.

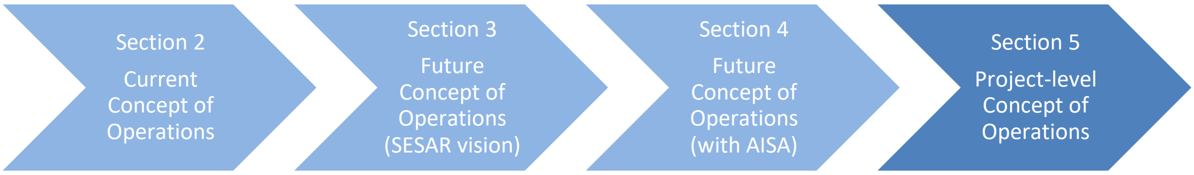
According to that, the section provided an overview of the human-machine distributed situational awareness concept, a list of technical prerequisites for implementing the AISA, description of the building blocks of artificial situational awareness which include knowledge graphs and reasoning engine combined with machine learning, conceptual description of the system and description of general architecture of the proposed system. At the end of the section, the description of the human role in the proposed concept of operations is provided.

The proposed system will at first be able to automate just some of the monitoring tasks because machines cannot currently reach the same level of awareness as humans, but as the development continues it will be able to take over more complex tasks. In later stages, the system will be aware of the traffic situation, its own state and other team member’s states. Therefore, it is not a system that will be built during this project but a vision of the future possible system if this project proves its feasibility and if the development continues.

At the core of the proposed system concept are controllers joined by AI. In order for this system to work, several prerequisites for implementing AISA were proposed, including SWIM, AIXM, FIXM and CPDLC. In addition to that, enabling human-machine SA requires that both entities have access to the same data. This would mean a connection must be formed between data for human use and data for machine use. In this way the system develops knowledge bases which represent the collections of organized data, where all relevant facts and rules will be encoded in a knowledge graph. Knowledge graph contains factual knowledge organized in a set of named graphs. Based on knowledge graphs, machine learning and reasoning engine will be used, in order for the system to be aware of the situation in a manner similar to a human, while AI assesses complex interactions between objects, draws conclusions and explains the reasoning behind those conclusions, and predict future system states.

It is expected that the research activities conducted in this project will show that such system is possible in a very specific environment such as en-route air traffic control operations, however, reaching higher levels of situational awareness will be possible only after further development.

# 5 AISA Project-level Concept of Operations




In the previous section, an overview of the AISA Concept of Operations as targeted for the year 2035 and onwards was presented. In this section, the project-level concept of operations is described. Whereas the future concept of operations is vague due to long time horizon of the predicition and unknown details of the future technology landscape, the project-level concept of operations is more detailed and lower level.

The purpose of the concept of operations is to describe how the operations will be performed. Usually, that description is focused on the interface between the human and the machine, defining what information will be presented to whom and how the user will need to use that information to make the decision and take actions. Here, however, the project is at the exploratory stage and the proposed proof-of-concept system will be developed to a very low technology readiness level (TRL). Interaction with the user is thus not prioritized as the main goal of the project is to determine if the concept of shared artificial situational awareness is feasible. Therefore, the concept of operations as described in this section will be focused more on the technology used and the capabilities thereof. Since the end goal, in the scope of the project, is not to develop a system with which the user will interact in real-time and it will not be used as a simulator, but to develop and assess the concept of the artificial SA based on the knowledge-graph, the interaction with the proof-of-concept system will take place in the command line, the system will operate in slower than real-time, and the analysis of the results will be performed off-line (post-processing).

## 5.1 Proof-of-Concept Knowledge-based System

In the previous section, a conceptual design of the system as imagined in the 2035 was presented. Here, a more in-depth description of the proof-of-concept (PoC) knowledge-based system as planned to be created in this project is described. The purpose of this system is to explore the feasibility of the concept by developing and testing crucial components of the future system. Cetainly, the scale of the PoC system is much smaller than that of the possible future system, however, the development of individual components and their integration will be extremely useful in showing whether the concept can be developed further. The overiew of the PoC system is shown in Figure 14. Details of the system will be explained in the following sub-sections.

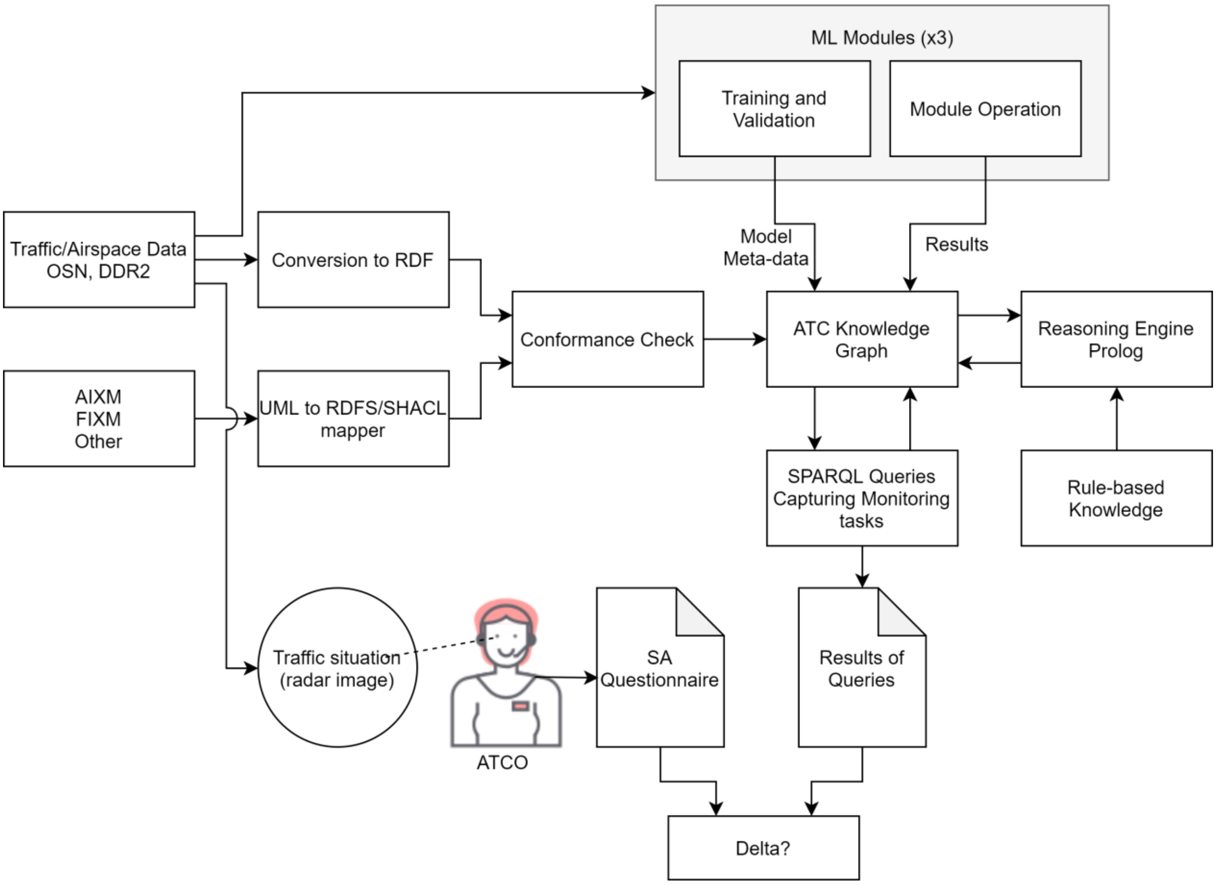



**Figure 14 Conceptual diagram of a Proof-of-Concept Knowledge-based System**

The PoC system has several major differences from the fully developed system as imagined in the previous section:

- Instance data will not be automatically generated. Whereas in the fully-developed system knowledge-graph will be populated automatically by directly translating the data provided in the exchange models, in the PoC system it will be populated by manually creating the named graphs and importing them into the KG-based system.
- Scale of the PoC system will be limited. The PoC system will be tested on a single sector with data from a single AIRAC cycle. In the fully-developed system KG will be populated with more knowledge.
- User interface will be limited. Querying the KG will be done via command-line interface and results will be displayed in the same manner. Whereas that is sufficient for exploratory research, for the future system that approach is unusable and all data should be presented to the ATCO in a user-friendly way.
- PoC system will not be real-time. While performance of the PoC system will be measured and reported, it will not be the main goal of the system development to improve the performance. Therefore, some of the queries or other processes might take more time than is practical in

actual operations. This drawback could be removed in the actual system by advanced optimisation, architectural changes and improved hardware.

### 5.1.1 Populating the Knowledge-graph

The central part of the PoC system is the ATC knowledge-graph. It will be populated by knowledge from different sources. As mentioned previously, the AISA project aims to leverage the aeronautical exchange models which already contain semantic information. We will develop a mapping from Unified Modeling Language (UML) class diagrams, as used in the aeronautical exchange models (e.g. AIXM, FIXM), to a vocabulary in RDFS (Resource Description Framework Schema) and structural constraints in SHACL (Shapes Constraint Language). The UML-to-RDFS/SHACL mapper will take, for example, a subset of AIXM as input and produce a corresponding RDFS vocabulary and SHACL constraints (Figure 15). The vocabulary and constraints may be later extended, directly in RDFS and SHACL or by making changes in UML and re-starting the mapping (without overwriting changes already made in RDFS and SHACL).

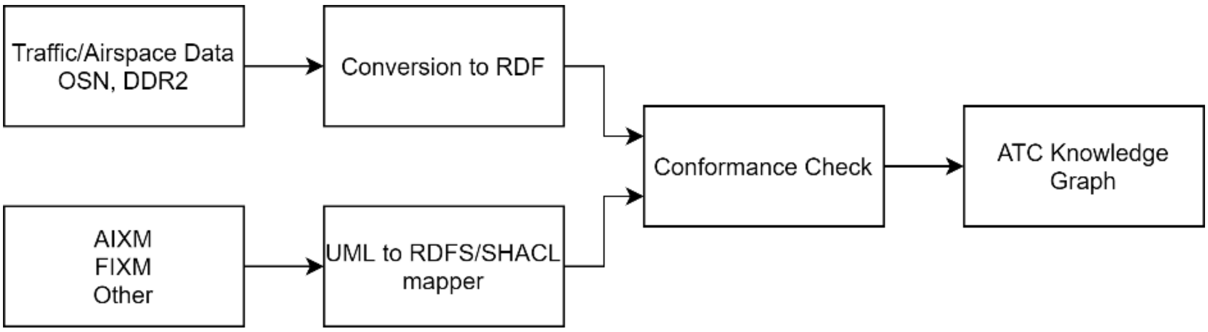



**Figure 15 Populating the Knowledge-graph**

Ontologies in RDF schema specify the semantics of classes and properties in a vocabulary and let the reasoner and the SPARQL (pronounced "sparkle", a recursive acronym for SPARQL Protocol and RDF Query Language) engine infer additional facts but they do not provide means to specify structural constraints. For example, in RDF one can state that every aircraft has a wingspan and a weight, but one cannot state that every aircraft in the knowledge base must have asserted in the knowledge base its wingspan and its weight. SHACL is a recent W3C recommendation to overcome this limitation. A SHACL processor takes a data graph (some part of a knowledge graph) and a shapes graph (a set of structural constraints encoded in RDF) as input and checks whether the data adheres to the constraints and produces a validation report (also in RDF) describing all violations.

The UML-to-RDFS/SHACL mapper will create RDF schema from the aeronautical exchange models and thus specify the semantics but it will not create instance data for a specific traffic situation. To create instance data (data related to a specific situation) it is necessary to translate the existing data sources into RDF. In this project the instance data will be created manually based on various data sources. Automatic translation of instance data will be preferable in the actual system, however, for the small-scale concept assessment purposes manual creation will be sufficient. Instance data will be created for a single en-route sector in Swiss airspace (LSAZM567, Figure 16) because the ATCOs participating in the concept evaluation will be Swiss controllers from Skyguide. Airspace data will be gathered from the Swiss Aeronautical Information Publication (AIP) and traffic information from the OpenSky Network (OSN) and DDR2. Traffic information will be based on the AIRAC 1907 as it represents the pre-COVID traffic well. Other data, such as aircraft performance or Letters of Agreement data, will also be added to the knowledge graph. For this data, however, exchange models do not exist so they will have to be directly defined in RDF or by using custom UML diagrams. All instance data will be checked for consistency with the schema by an automatic conformance checker. *Apache Jena* will be used to store and query the knowledge-graph.

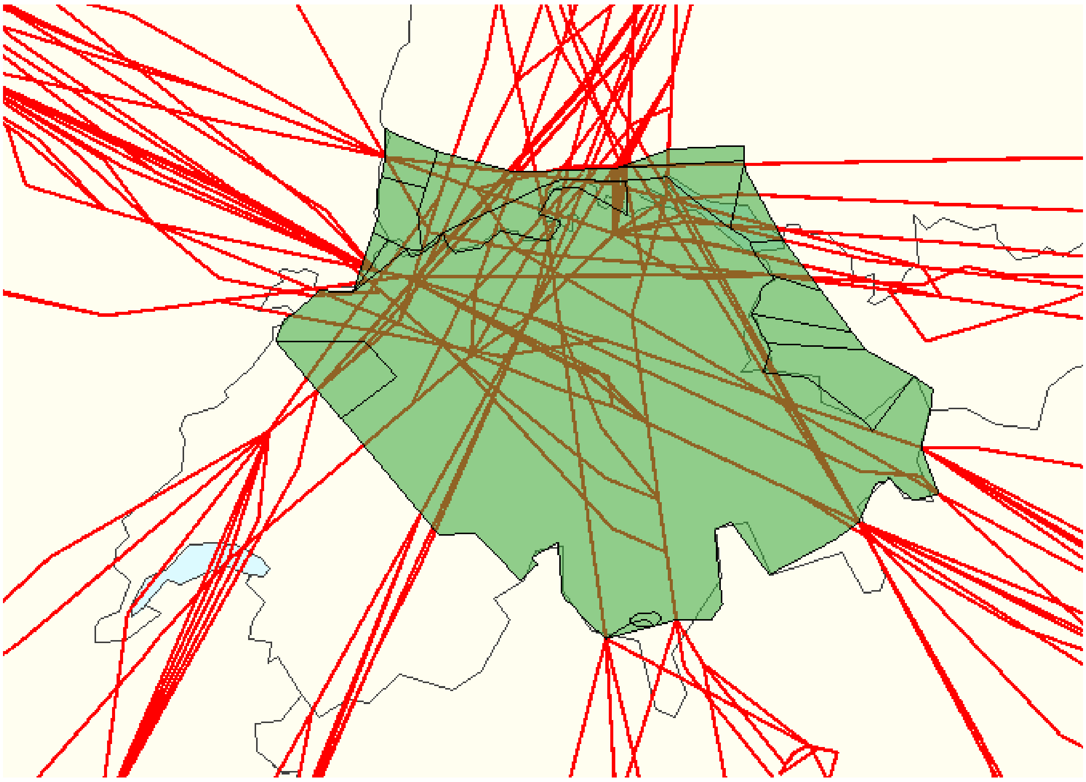


**Figure 16 Swiss Sector LSAZM567, FL355-999, With 1 Hour of Traffic Shown**

### 5.1.2 Rule-based Knowledge

In addition to factual knowledge in a knowledge graph, a knowledge-based system needs to manage and execute rule-based knowledge. Rule-based knowledge is defined and executed on top of the factual knowledge in the knowledge graph. There are many different rule-based formalisms, many rooted in Datalog, all coming with their advantages and limitations. In AISA a key requirement is to have a flexible approach to rule-based reasoning, to be able to fulfil also unforeseen requirements which will emerge during the project. Prolog, more exactly, the versatile and tried and tested SWI-Prolog system, facilitates such a flexible approach. Example of the rules that can be stored and used to assess the situation are those related to separation provision. The knowledge-graph itself cannot be used to determine whether two aircraft are safely separated or not. Such rules will be developed with the help of the domain experts, mainly ATCOs and ATM experts.

The challenge now is to make reading and writing the KG from Prolog as easy as possible. One way would be to access knowledge in triple form, using Prolog not only as a rule language but also as a query language for KGs, but then we would not take advantage of the convenience and power of SPARQL (a query language specifically designed for KGs). Fortunately, SWI-Prolog comes with a SPARQL client library which allows to read and write knowledge graphs from Prolog via SPARQL queries and updates. Using the SPARQL client library without further support, however, knowledge engineers would end up producing a lot of intricate boilerplate code, writing SPARQL queries and for reading out the SPARQL results into Prolog predicates. The KG-Prolog mapper will reduce the workload of knowledge engineers by automatically translating SHACL shapes (sets of related structural constraints) over classes and properties defined in RDFS to Prolog predicates, associated SPARQL queries (or update requests), as well as Prolog code for populating a predicate with the results of its associated SPARQL query (or executing a SPARQL update request with a Prolog predicate's extent as input).

### 5.1.3 Integration of ML Modules

One of the uses of the AISA system will be to help integrate information from diverse sources into a single semantic representation. Some of the sources, such as aeronautical information publications, provide information of the highest integrity; information that does not need to be checked by the user. When using such information ATCOs will not think twice whether it is correct or not. On the other hand, some source of information are not as trustworthy. These are mainly sources related to prediction or some sort of forecast (e.g. weather forecast, conflict detection) and those predictions might not, and often do not, come true. Combining both types of information in one display may cause ATCOs to become annoyed or to disregard information deemed unreliable altogether. Checking the plausibility of a tool's result increases the mental workload for ATCOs which is especially perilous in traffic situations with many complex interactions. With increased adoption of ML-based tools, it can only be expected that the ATCOs will have to perform increasing number of plausibility checks of results provided by different tools in the future.

The process that controllers use to check if the information provided by a tools is plausible is based on comparing that information with information and knowledge gained from a different source with higher integrity. ATCOs might use reliable source of information, such as aircraft's radar position or altitude, or they might use their previously acquired knowledge, such as aircraft performance data, to compare the less reliable information with. For example, information provided by the conflict detection tool for an aircraft in climb might be deemed unreliable if the ATCO is certain that the climbing aircraft is physically unable to reach the flight level at which the conflict is supposed to take place.

Similarly, using knowledge, facts and rules of higher integrity to check the plausibility of results given by the ML modules is the approach taken in this project. For a given traffic situation, predictions and assessment based on the machine learning will be integrated into the knowledge graph. Querying the KG in a way that is designed to expose possible inconsistencies can give some ideas about the plausibility of the ML module results. Another approach, which is very much different from the way humans assess the information, will be used as well. In this approach, for each ML module, complete model meta-data will be provided to the KG. Meta-data will include description of the module including the description of the data used for the training of the ML module. This will help for assessment whether the inputs provided to the ML module are something for which the module was trained before (Figure 17). For example, such meta-data might contain the list of aircraft types which were used for the training of the trajectory prediction tool. During the operation, if the input includes a completely new aircraft type, the result could be considered less trustworthy.

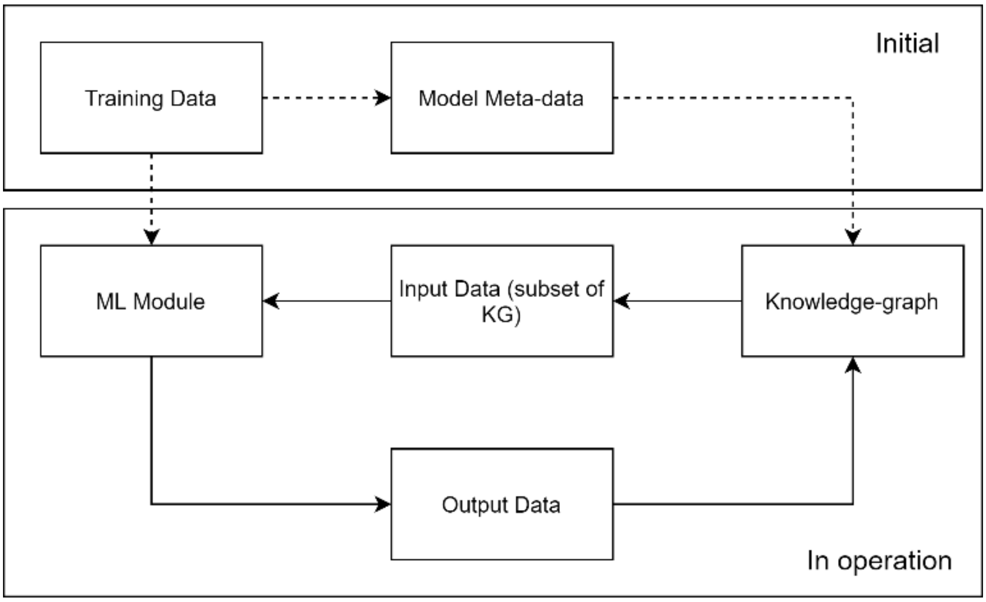



**Figure 17 Integration of ML Modules with Knowledge-graph**

Three ML modules will be produced: trajectory-prediction module, conflict detection module, and complexity assessment module. Each of the modules will use different ML techniques to achieve their goals and, within the project, they will be developed without cooperation with each other in order to simulate products from different vendors.

Modules will be trained and validated with separate sets of OpenSky Network ADS-B data. Complete set of values for each of the input variables used for training will be analyzed and statistically described. Description of the training variables will make most of the model meta-data and will be used to determine the compatibility of the input data used during the model operation with the input data used during the training. In operation, SPARQL query will be used to extract the relevant data from the KG and a simple tool will translate that data into a format appropriate for the ML module. Once the ML module produces its output it will again be translated into RDF so that it can be imported back into the KG where further reasoning will take place.

## 5.2 Tasks to be Automated

In Section 4.5.1.1, a list of possible uses for AISA in the future ConOps was presented. Since it was based on the SESAR ConOps for 2035, with a lot of assumptions which might not be correct, the tasks were described on a general level. In this section, a more detailed look at the tasks which we will attempt to automate within the framework of the PoC KG-based system is given. Because the PoC system will not have all the capabilities of the proposed future system and the level of the artificial situational awareness will not be nearly as high as that of an ATCO, tasks thus selected are only a subset of all possible tasks that could be automated. Most of the tasks presented are monitoring tasks but there are also some tasks that include prediction and decision-making. For each category of tasks, a set of representative tasks is shown.

| Task Category | Task |
|---|---|
| 1. Conformance management | |
| | 1.1. Check that aircraft is Climbing/descending towards cleared FL<br>1.2. Check that aircraft is at cleared FL<br>1.3. Check that aircraft is maintaining FL |
| | 1.4. Check that aircraft is turning towards/opposite of cleared heading<br>1.5. Check that aircraft is at cleared heading<br>1.6. Check that aircraft is maintaining current heading (different than cleared heading) |
| | 1.7. Check that aircraft is accelerating/decelerating towards cleared speed<br>1.8. Check that aircraft is flying at cleared speed<br>1.9. Check that aircraft is maintaining current speed (different than cleared speed) |
| | 1.10. Check that aircraft is flying towards cleared point<br>1.11. Check that aircraft is at cleared point |
| | 1.12. Check that aircraft's current ROC/ROD is lower/higher than cleared<br>1.13. Check that aircraft is maintaining cleared ROC/ROD<br>1.14. Check that aircraft is increasing/decreasing towards cleared ROC/ROD |
| | 1.15. Check that aircraft is following the 3D trajectory<br>1.16. Check if the deviation from 3D trajectory is within tolerance |
| | 1.17. Check that aircraft is following the 4D trajectory<br>1.18. Check if the deviation from 4D trajectory is within tolerance |
| 2. Detect Incoming Planned Flights | |
| | 2.1. Check that aircraft is close to Sector boundary<br>2.2. Check that aircraft is approaching Sector boundary |
| | 2.3. Check that aircraft's altitude is within the altitude band of the Sector<br>2.4. Check that aircraft's altitude is approaching the Sector altitude |
| 3. Assume, Identify, and Confirm Flight | |
| | 3.1. Check that aircraft is incoming<br>3.2. Check that aircraft is planned |

| | |
|---|---|
| | 3.3. Check that aircraft has sent the initial call (via datalink)<br>3.4. Confirm that aircraft can be assumed |
| 4. Assess if Exit Conditions are Met | |
| | 4.1. Check that aircraft is flying towards the exit point<br>4.2. Check that aircraft will reach the exit point on the required FL<br>4.3. Check that aircraft will reach the exit point at the expected time |
| 5. Conflict Management | |
| | 5.1. Check all aircraft pairs for conflict (ML module)<br>5.2. Check plausibility of the predicted conflicts<br>5.3. Check which conflicts are to occur within the sector<br>5.4. Rank conflicts based on urgency |
| 6. Execute Aircraft's Plan | |
| | 6.1. Detect aircraft that have to climb/descend to requested FL<br>6.2. Detect aircraft that have to climb/descend to exit FL<br>6.3. Detect aircraft that will reach top of descent within the Sector (ML module)<br>6.4. Detect if planned trajectory passess through restricted airspace |
| 7. Transfer Aircraft | |
| | 7.1. Check which aircraft need to be transferred<br>7.2. Check if change of frequency is issued to A/C (via datalink)<br>7.3. Change aircraft status to transferred |
| 8. Maximise Quality of Service | |
| | 8.1. Detect direct-to candidates<br>8.2. Determine military airspace availability<br>8.3. Check suggestion for shortened RBT |
| 9. Workload Monitoring | |
| | 9.1. Track current number of assumed aircraft<br>9.2. Track number of conflicts and potential conflicts<br>9.3. Determine future number of sector entries |
| | 9.4. Determine sector air traffic complexity (ML module)<br>9.5. Determine plausibility of traffic complexity assessment |
| 10. Identify Missing Information | |

| | |
|---|---|
| | 10.1. Identify aircraft with possible equipment degradation<br>10.2. Check situation at destination airport<br>10.3. Check situation at alternate airports<br>10.4. Monitor adverse weather areas<br>10.5. Monitor restricted airspace<br>10.6. Infer missing information |
| 11. Monitor Status of ATC Sub-systems | |
| | 11.1. Monitor performance of ATC conflict detection module<br>11.2. Monitor performance of complexity assessment module<br>11.3. Monitor performance of trajectory prediction module |

**Table 11 Tasks to be Automated by PoC KG-based System in AISA**

## 5.3 SA Assessment

To assess the concept, it will be necessary to determine whether the developed system possesses a quality which is comparable to the human situational awareness. Certainly, artificial SA will not be nowhere nearly as comprehensive as human, however, we expect that reaching partial SA will be enough to prove the feasibility of the concept. Baseline for comparison will first have to be developed by assessing ATCO's SA in a set of given air traffic situations and then compared to artifical SA which will be generated by SPARQL queries (Figure 18).

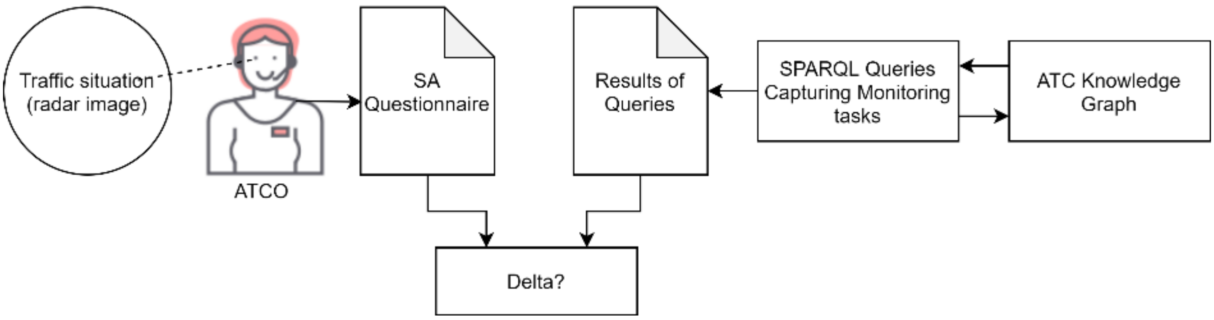



**Figure 18 Comparison of Human and System SA**

### 5.3.1 Human SA

There are a number of SA assessment tools, which have been developed over the years. According to [45] the measures can be grouped into three categories:

- query techniques, in which the subjects are asked directly about their perception of certain aspects of the situation : Situation Awareness Global Assessment Technique (SAGAT), Situation Present Assessment Method (SPAM), Situation Awareness bei Fluglotsen der

Langstreckenkontrolle im Kontext von Automatisierung (SALSA), Situation Awareness Probe S (SPAPS)
- rating techniques, in which either the subjects themselves, or observers of the subjects, are asked to rate SA along a number of dimensions, typically presented in a series of scales: Situation Awareness Rating Technique (SART), Cranfield Situation Awareness Scale (C-SAS), Situation Awareness Linked Indicators Adapted to Novel Tasks (SALIANT), Situation Awareness Behaviorally Anchored Rating Scale (SA/BARS)
- performance-based techniques, in which the level of SA is inferred from the level of performance. The rationale underlying this technique is that good SA is needed to achieve a good performance. This might be the use of objective measurement tools techniques like eye tracking.

Taken into account the previous existing SA measurement tools, [45] developed two specific kinds of measurement tools to assess ATCO`s SA in Air Traffic Management (ATM). The first one is SA for Shape on-Line (SASHA_L), which is a query technique based on existing measure, especially SPAM. The new component of this SA assessment tool is, that the queries are formulated by a subject matter expert (SME) in real-time, taking into account the real scenario as it unfolds. Thus, the SME asks a question when he/she decides it is pertinent to do so. The second measurement tools is SA for SHAPE Questionnaire (SASHA_Q) – a questionnaire technique using carefully chosen questions that focus on key elements of SA which controllers have identified themselves. The SASHA_Q is a post-exercise self-rating technique. It consists of ten questions that were especially designed by taking into account the views of controllers themselves about SA and its indicators. Both measures are primarily concerned with controllers` SA when using computer-assistance tools and other forms of automation support.

By assessing SA in ATCO’s it seems reasonable and useful to use different kinds of measurement tools as proposed by [45]. The use of SASHA_L and SASHA-Q in combination with an objective measurement tool like eye tracking (to assess perception modes) seems appropriate when studying SA in the mentioned context of the herein proposed research.

### 5.3.2 Artificial SA

Artifical SA will be assessed in two ways: by assessing properties of the system alone and by comparing the results given by the system with answers given by the ATCOs.

To assess the artificial SA in terms of its properties, we formulate our framework according to Jantsch and Tammemäe [46]. We shall define the system aware of certain characteristics of the environment, if the following three conditions are met:

- The data can be meaningfully interpreted;
- The drawn conclusions are robust; and
- There is an appropriate reaction of the system [46].

Based on these three rules, we can define five conditions for being aware of the environment and two conditions for being aware of itself. For property P (e.g. an event which triggers an ATC task), we define following conditions related to awareness of said property by the system [46]:

I. The system makes physical measurements or observations based on received measurement that are used to derive the values of P by means of a meaningful semantic interpretation.
II. The semantic interpretation is robust.
III. There is a meaningful semantic attribution.
IV. The system is able to appropriately react to its perception of P.
V. The record of the evolution of the property over time is kept, especially of the varying deviations over time [46].

As mentioned previously, we also define two conditions for being aware of itself. The first condition (A) is that the system is capable of self-assesment, thus it understands which goals it should achieve, as well as to which degree they are achieved. The second defined condition (B) is that the system can evaluate how well the goals are reached over time and when its performance is improving or degenerating [46].

This framework enables us now to define six levels of SA, as seen in Table 12 below with examples from AISA tasks.

| SA Level | Description | AISA Example |
|---|---|---|
| 0 | A functional system's output is a mathematical function of its input. It always has an identical reaction to a given input. If it also satisfies the conditions I – IV, we define it to be at Level 0. | • Determine the distance between two aircraft<br>• Detect separation minima infringement |
| 1 | An adaptive subject attempts to minimize the discrepancies between input values and corresponding reference values. If it also meets conditions I – IV it is aware at level 1. | • In the PoC system AISA will not be able to make actions but it will be able to suggest actions |
| 2 | A self-aware system<br>1. is aware of at least one system property and one environment property as per conditions I – IV and condition A,<br>2. involves an inspection engine that periodically derives one integrated attribution of the system, and<br>3. determines its actions based on<br>• the observed and attributed properties of the system and of the environment;<br>• the attributed expectations on the system and on the environment;<br>• the set of goals set for the system and the environment. | • Example of a system property of which the system is aware all the time is internal consistency in the KG. All knowledge related to airspace and traffic are environment properties.<br>• Inferred knowledge is derived by reasoning engine<br>• Suggesting transfer of aircraft is done based on the current aircraft position (observed property of the environment), location of sector boundary (system property in the general sense of the term system), procedure for transfer (expectation of the system), and orderly flow of traffic (goal). |

| | | |
|---|---|---|
| 3 | A history sensitive self-aware system meets all requirements of Level 2 and, additionally, fulfills the history conditions V and B (thus satisfying all seven conditions). | • History of the properties are stored in named graphs for the previous chronons.<br>• Whether the goal (e.g. safe separation maintained) is reached is also stored in named graphs. |
| 4 | A predictive system is a history sensitive self-aware system of Level 3. It includes a simulation engine in its decision-making process. The engine is capable of predicting future states of both the system and its environment by simulating the effects of actions on the environment and the system. In case there is a contradiction between predicted and measured state, the system starts to seek for the best match according to current situation. The simulation engine chooses the simulation scenarios and then decides which actions will be taken based on the outcomes of the simulations. | • KG-based systems on their own are not useful for prediction, therefore AISA uses ML modules for that (trajectory prediction, conflict detection). |
| 5 | Group awareness means that the system is not only self-aware, but is able to differentiate between itself, the environment and the peer group, which is associated with peer group specific expectations and goals. | • Air traffic complexity assessment is an example of AISA's capability to determine possible states of the peer group (ATCOs). |

**Table 12 Proposed framework for assessment of artificial SA (adapted from [46] )**

In addition to artificial SA assessment according to the framework above, assessment will be made in comparison to ATCOs SA. Assessment of the SA level will be performed by writing SPARQL queries designed to elicit the same information such as those that the ATCO will be asked in SASHA_L/Q. These queries will be focused on analyzing the traffic situation in en-route ATC. The purpose of these queries will be to determine whether the system can gain insights into the extent of team SA and state of other actors. List of questions given to the ATCOs will be made available to the knowledge engineers as well who will then attempt to formulate appropriate queries. Fraction of the successfully answered queries will determine the similarity of the artificial and human SA. Overall, this methodology, and the concept itself, has not been used before so many questions still remain unanswered and must be studied further.

## 5.4 Conclusion

In this section we have presented the project-level concept of operations for AISA. The main goal of the project is to determine if the concept of shared artificial situational awareness is feasible. The tool which will help us determine that is the proof-of-concept knowledge-based system as described in this section. We have shown the structure of the system, development process, technologies used, and the main set of tasks that it should be able to perform. Finally, we have described the methodology for assessment of the concept which will give us objective insight into the good and bad sides of the concept.

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# Appendix A Glossary

| Abbreviation | Term |
|---|---|
| ACAS | Enhanced Airborne Collision Avoidance for Commercial Air Transport Normal Operations |
| ACC | Area Control Center |
| ACL | AT Clearances Service |
| ACM | ATC Communications Management Service |
| ADS | Automatic Dependent Surveillance |
| ADS-B | Automatic Dependent Surveillance-Broadcast |
| ADS-B IN/OUT | Automatic Dependent Surveillance-In/Out |
| ADS-C | Automatic Dependent Surveillance-Contract |
| ADSP | ATM Data Service Providers |
| AGI | Artificial General Intelligence |
| AI | Artificial Intelligence |
| AIM | Aeronautical Information Management |
| AIP | Aeronautical Information Publications |
| AIXM | Aeronautical Information Exchange Model |
| AMC | ATC Microphone Check Service |
| AMSL | Above Mean Sea Level |
| ANS | Air Navigation Services |
| ANSP | Air Navigation Service Provider |
| APM | Approach Path Monitor |
| APW | Area Proximity Warning |
| ARES | Airspace Reservation |
| ASM | Airspace Management |
| ATC | Air Traffic Control |
| ATCO | Air Traffic Control Officer |
| ATFM | Air Traffic Flow Management |
| ATM | Air Traffic Management |
| ATS | Air Traffic Service |
| AUTOPACE | Automation pace |
| CAA | Civil Aviation Authority |

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| CARD | Conflict and Risk Display |
| CDM | Collaborative Decision Making |
| CLAM | Cleared flight Adherence tool |
| CNS | Communications, Navigation and Surveillance Systems |
| ConOps | Concept of Operations |
| CPDLC | Controller Pilot Data Link Communications |
| DAC | Dynamic Airspace Configurations |
| DAP | Downlinked Aircraft Parameters |
| DCB | Demand Capacity Balancing |
| DCL | Departure Clearance |
| DLIC | Data Link Initiation Capability |
| ECAC | European Civil Aviation Conference |
| EOC | Essential Operational Change |
| EPP | Extended Projected Profile |
| ERNIP | European Route Network Improvement Plan |
| ETO | Estimated Time Over |
| EXE | Executive Controller |
| FAA | Federal Aviation Administration |
| FAB | Functional Airspace Block |
| FIR | Flight Information Region |
| FIXM | Flight Information Exchange Model |
| FMP | Flow Management Position |
| FMS | Flight Management System |
| FMTP | Common Flight Message Transfer Protocol |
| FPS | Flight Progress Strip |
| FRA | Free Route Airspace |
| FUA | Flexible Use of Airspace |
| H24 | 24 Hours a day operation |
| HF | High Frequency |
| HIC | Human in command |
| HITL | Human in the loop |
| HMI | Human-machine interface |
| IAS | Indicated airspeed |

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| ICAO | International Civil Aviation Organization |
| IFF | Identification Friend or Foe |
| IFR | Instrument flight rules |
| INAP | Digital Integrated Network Management and ATC Planning |
| IP | Internet Protocol |
| ISOBAR | Artificial Intelligence Solutions to Meteo-Based DCB Imbalances for Network Operations Planning |
| KG | Knowledge graph |
| KPA | Key Performance Area |
| KPI | Key Performance Indicator |
| LoA | Letters of Agreement |
| MAHALO | Modern ATM via Human/Automation Learning Optimisation |
| MET | Meteorological service for air navigation |
| MINIMA | Mitigating negative impacts of monitoring high levels of automation |
| MLAT system | Multilateration |
| MSAW | Minimum Safe Altitude Warning |
| MSP | Multi-Sector Planner |
| MTCD | Medium-Term Conflict Detection |
| MTOM | Maximum TakeOff Mass |
| NDB | Non-Directional Radio Beacon |
| NM | Nautical Mile |
| NOP | Network Operations Plan |
| OAC | Oceanic Area Control Centre |
| OAT | Operational Air Traffic |
| OOTL | Out-of-the-loop |
| OSN | OpenSky Network |
| PHARE | Program for Harmonized ATM Research in EUROCONTROL |
| PiC | Pilot in-command |
| PLC | Planning Controller |
| PoC | Proof-of-Concept |
| PSR | Primary Surveillance Radar |
| QDM | Range and Bearing tool |
| R&D | Research and Development |
| RAM | Route Adherence tool |

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| RBT | Reference Business Trajectory |
| RDF | Resource Description Framework |
| RDFS | Resource Description Framework Schema |
| RECAT | Re-Categorisation |
| RNP | Required Navigation Performance |
| RVSM | Reduced Vertical Separation Minimum |
| SA | Situational Awareness |
| SAGAT | Situation Awareness Global Assessment Technique |
| SAP | Segregated Area Probe |
| SART | Situation Awareness Rating Technique |
| SATCOM | Satellite Communication |
| SEP | Separation display tool |
| SES | Single European Sky |
| SHACL | Shapes Constraint Language |
| SPAM | Situation Present Assessment Method |
| SPARQL | SPARQL Protocol and RDF Query Language |
| SSR | Secondary Surveillance Radar |
| STCA | Short Term Conflict Alert |
| SVFR | Special VFR |
| SWIM | System-wide Information Management |
| TAPAS | Towards an Automated and exPlainable ATM System |
| TBO | Trajectory Based Operations |
| TBS | Time-Based Separation |
| TCM | Traffic Complexity Management |
| TCT | Tactical Controller Tool |
| TLS | Tactical Load Smoother |
| TMA | Terminal Control Area |
| TPI | Trajectory Prediction Improvement |
| UHF | Ultra-high frequency |
| UML | Unified Modeling Language |
| VAC | Vigilance and Attention Controller |
| VFR | Visual Flight Rules |
| VHF | Very high frequency |

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| VMC | Visual Meteorological Conditions |
| VOR | Very High-Frequency Omnidirectional Radio Range |
| XAI | eXplainable Artificial Intelligence |

**Table 1 Table of acronyms**

| Term | Definition |
|---|---|
| 24 Hours a day operation | A service that is available at any time and usually, every day |
| 4D Trajectory | The 4D trajectory of an aircraft consists of the three spatial dimensions plus time as a fourth dimension. This means that any delay is, in fact, a distortion of the trajectory as much as a level change or a change of the horizontal position. Tactical interventions by air traffic controllers rarely take into account the effect on the trajectory as a whole due to the relatively short look-ahead time. Source: SKYbrary |
| Above Mean Sea Level | Mean sea level (MSL) (often shortened to sea level) is an average level of the surface of one or more of Earth's bodies of water from which heights such as elevation may be measured. The global MSL is a standard sea level at which atmospheric pressure is measured to calibrate altitude and, consequently, aircraft flight levels. Height above mean sea level (AMSL) is the altitude of an object, relative to the average sea level datum. Source: ICAO |
| Aeronautical Information Exchange Model | A logical data model and data exchange specification for aeronautical information, which is the standard used for digitally encoding, processing and distributing aeronautical data by Aeronautical Information Services (AIS) in Europe; initially developed by EUROCONTROL for the European AIS Database (EAD), AIXM has gradually become a world-wide standard, the latest model versions being co-developed with United States FAA and in the process to be adopted by ICAO. Source: EUROCONTROL and FAA |
| Aeronautical Information Management | The dynamic, integrated management of aeronautical information services through the provision and exchange of quality-assured digital aeronautical data, in collaboration with all parties. Source: EUROCONTROL |
| Aeronautical Information Publications | A publication issued by or with the authority of a State and containing aeronautical information of a lasting character essential to air navigation. Source: ICAO |
| AI Situational Awareness System | The operating system that will be implemented by ATM system providers in the future. It means the future ATC system together with an AISA AI engine. In some cases, the system is referred as "AI based support system", and the "system". |
| Air Navigation Service Provider | 1. Any public or private entity providing air navigation services for general air traffic  Source: EUROCONTROL<br>2. A body that manages flight traffic on behalf of a company, region or country. Source: ICAO |

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| Air Navigation Services | Services provided to air traffic during all phases of operations including air traffic management, communication, navigation and surveillance, meteorological services for air navigation, search and rescue and aeronautical information services. Source: ICAO |
| Air Traffic Control | A service operated by appropriate authority to promote the safe, orderly and expeditious flow of air traffic. Source: FAA |
| Air Traffic Control Officer | 1. A person authorized to provide air traffic control services. Source: ICAO<br>2. An air traffic controller, qualified following Annex 1 — Personnel Licensing, and holding a rating appropriate to the assigned functions. Source: ICAO<br>3. Air traffic controllers manage aircraft through all phases of flight, with a stress on safety, orderliness and efficiency. In their doing so, they use various means of communication, navigation and surveillance to give information, instructions and clearances to pilots. Source: Croatia Control |
| Air Traffic Flow Management | 1. A function established with the objective of contributing to a safe, orderly and expeditious flow of air traffic by ensuring that ATC capacity is utilised to the maximum extent possible and that the traffic volume is compatible with the capacities declared by the appropriate air traffic service providers. Source: EUROCONTROL<br>2. A service established with the objective of contributing to a safe, orderly and expeditious flow of air traffic by ensuring that ATC capacity is utilized to the maximum extent possible and that the traffic volume is compatible with the capacities declared by the appropriate ATS authority. Source: ICAO |
| 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 efficiently — through the provision of facilities and seamless services in collaboration with all parties and involving airborne and ground-based functions. Source: ICAO |
| Air Traffic Services | 1. The availability of one or more flight information services, alerting services, air traffic advisory services, and/or air traffic control services (for example: area control services, approach control services, and aerodrome control services). Source: AIFDD<br>2. A generic term meaning variously flight information service, alerting service, air traffic advisory service, air traffic control service (area control service, approach control service or aerodrome control service) and aerodrome flight information service. Source: ICAO |
| AIRborne Information for Emergency Situation Awareness and Monitoring | The AIRBEAM project proposes a situation awareness toolbox for the management of crisis over wide area taking benefit of an optimised set of aerial (unmanned) platforms, including satellites. Source: Cordis |
| Airspace Management | A planning function with the primary objective of maximizing the utilization of available airspace by dynamic time-sharing and, at times, the segregation of airspace among various categories of users based on short-term needs. Source:ICAO |
| Airspace Reservation | A defined volume of airspace temporarily reserved for exclusive or specific use by categories of users. These airspace reservations may be stationary, like an "ad- |

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| | hoc" TSA, or moving along with the flight path to facilitate aerial operations like en-route Air to Air Refuelling. Source: SESAR |
| Approach Path Monitor | A ground-based safety net intended to warn the controller about an increased risk of controlled flight into terrain accidents by generating, in a timely manner, an alert of aircraft proximity to terrain or obstacles during final approach. Source: EUROCONTROL |
| Area Control Center | A unit established to provide air traffic control service to controlled flights in control areas under its jurisdiction. Source: ICAO |
| Area Proximity Warning | A ground-based safety net intended to warn the controller about unauthorised penetration of an airspace volume by generating, in a timely manner, an alert of a potential or actual infringement of the required spacing to that airspace volume. Source: EUROCONTROL |
| Artificial Intelligence | The ability of a digital computer or computer-controlled robot to perform tasks commonly associated with intelligent beings. The term is frequently applied to the project of developing systems endowed with the intellectual processes characteristic of humans, such as the ability to reason, discover meaning, generalize, or learn from past experience. Source: Britannica |
| Artificial Intelligence Solutions to Meteo-Based DCB Imbalances for Network Operations Planning | A project that falls under SESARJU optimised ATM network services. It aims to provide a service that is based on the AI Network Operations Plan (NOP) in a way that integrates enhanced forecasts regarding convective weather. Source: Cordis |
| ATC Clearances Service | Data link service that allows flight crews and controllers to conduct operational exchanges – flight crews can send requests and reports and controllers can issue clearances, instructions and notifications. Source: SKYbrary |
| ATC Communications Management Service | Data link service that provides automated assistance to flight crew and controllers for the transfer of ATC communications (voice and CPDLC). Source: SKYbrary |
| ATC Microphone Check Service | Data link service that allows controllers to send an instruction to all CPDLC capable aircraft on a given frequency (at the same time) to verify that their voice communication equipment is not blocking a given voice channel. Source: SKYbrary |
| ATM data service providers | An ADSP is an entity that will manage all (or part of) the data processing and associated support services needed by one or several Air Traffic Service Units to deliver ATS services. So for any given unit, flight data processing could be provided by one ADSP, whereas surveillance or meteorological data services could be provided by another - implying exchange of data between both ADSPs. In a different scenario, an ATC unit could have a single ADSP providing all real-time ATM data needed to deliver ATS services. Source: egis group |
| Automatic Dependent Surveillance | A surveillance technique in which aircraft automatically provide, via a data link, data derived from on-board navigation and position-fixing systems, including aircraft identification, four-dimensional position and additional data as appropriate. Source: ICAO |
| Automatic Dependent Surveillance-Broadcast | A means by which aircraft, aerodrome vehicles and other objects can automatically transmit and/or receive data such as identification, position and additional data, as appropriate, in a broadcast mode via a data link. Source: ICAO |

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| Automatic Dependent Surveillance-Contract | A means by which the terms of an ADS-C agreement will be exchanged between the ground system and the aircraft, via a data link, specifying under what conditions ADS-C reports would be initiated, and what data would be contained in the reports. Source: SESAR Concept of Operations |
| Automatic Dependent Surveillance-IN/OUT | ADS-B In provides operators of properly equipped aircraft with weather and traffic position information delivered directly to the cockpit and is the receiver part of the system. ADS-B Out works by broadcasting information about an aircraft's GPS location, altitude, ground speed and other data to ground stations and other aircraft, and is a transmitter. Source:FAA |
| Automation pace | AUTOPACE proposes basic research on a Psychological Model to quantitatively predict how automation would impact on human performance based on cognitive resources modelling (demanded and available), tasks characteristics (automation), psychological factors modelling (fatigue, stress and emotions) and ATCO expectations (overconfidence vs fears of automation). Source: Cordis.europa |
| Civil Aviation Authority | The governmental entity or entities, that are directly responsible for the regulation of all aspects of civil air transport, technical (i.e. air navigation and aviation safety) and economic (i.e. the commercial aspects of air transport). Source: ICAO |
| Cleared flight Adherence tool | Cleared Level Adherence Monitoring tool or CLAM is a tool that constantly monitors whether a flight actually keeps to the flight level it has been assigned by air traffic control. If the flight leaves this altitude, the controller responsible for it will be alerted to this immediately by a visual alarm. Source: Air Traffic Management Key Publishing |
| Collaborative Decision Making | A process focused on how to decide on a course of action articulated between two or more community members. Source: SESAR Concept of Operations |
| Common Flight Message Transfer Protocol | Flight Message Transfer Protocol is a communication stack based on the transmission control and internet protocols. It is used in a peer-to-peer communication context for the information exchange between flight data processing systems for the purpose of notification, coordination and transfer of flights between air traffic control units and for the purposes of civil-military cooperation. Source: EUROCONTROL |
| Common Flight Message Transfer Protocol | Flight Message Transfer Protocol is a communication stack based on the transmission control and internet protocols. It is used in a peer-to-peer communication context for the information exchange between flight data processing systems for the purpose of notification, coordination and transfer of flights between air traffic control units and for the purposes of civil-military cooperation. Source: EUROCONTROL |
| Communications, Navigation and Surveillance Systems | Communication, navigation and surveillance (CNS) are the main functions that form the infrastructure for air traffic management and ensure that air traffic is safe and efficient. Source: EUROCONTROL |
| Conflict | An event in which the time interval/distance/other parameters between two or multiple aircraft violate the normative separation. Source: Jun Tang: Conflict Detection and Resolution for Civil Aviation: A Literature Survey |

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| Conflict and Risk Display | CARD (Conflict and Risk Display) is a tool for visualization of a detected conflict. CARD will warn the ATCO by changing the colour of the conflict to indicate an increased or decreased severity of the situation. Source: |
| Controller Pilot Data Link Communications | A means of communication between controller and pilot, using data link for ATC communications. Source: ICAO |
| Data Link Initiation Capability | Data link service that provides the necessary information to make data link communications possible between an ATSU and aircraft. The DLIC service is executed prior to the first use of any other data link application. Source: SKYbrary |
| Demand Capacity Balancing | The DCB process considers two important types of objects in the ATM system: aircraft trajectories and airspace sectors, and is divided into three phases: Strategic, Pre-tactical and Tactical Phase. The overall objective is to optimize traffic flows according to ATC capacity while enabling airlines to operate safe and efficient flights. Source: Fernández E et al.: A Machine-Learning Approach to Trajectory Prediction and Demand-Capacity Balancing. |
| Departure Clearance | Data link service that provides automated assistance for requesting and delivering departure clearances to aircraft. Source: SKYbrary |
| Digital Integrated Network Management and ATC Planning | This Key R&D activity aims at filling the gap between the management of traffic flows at network level and the control of flights in individual sectors. This develops and integrates local functions and associated tools, roles and responsibilities providing an automated interface between local NM and ATC planning to assist controllers in alleviating traffic complexity, traffic density, and traffic flow problems. Source: SESAR |
| Downlinked Aircraft Parameters | Downlink Aircraft Parameters (DAPs) is one of Secondary Surveillance Radar (SSR) Mode S datalink functions. It enables a ground station to obtain real-time aircraft information such as selected altitude and ground speed. DAPs improves efficiency, capacity, and safety of Air Traffic Control (ATC) service. Source: Keisuke Matsunaga etl al. : SSR Mode S downlink aircraft parameters validation and evaluation |
| Downstream Clearance Service | Data link service provided for flight crews who are required to request and obtain clearances from ATS units that are not yet in control of the aircraft when they cannot get the clearance information via the current ATS unit through unit to unit coordination. Source: SKYbrary |
| Dynamic Airspace Configurations | Dynamic Airspace Configuration (DAC) is a new operational paradigm that proposes to migrate from the current structured, static airspace to dynamic airspace capable of adapting to user demand while meeting changing constraints of weather, traffic congestion and complexity, as well as a highly diverse aircraft fleet. Source: Kopardekar, P. et al.: Initial concepts for Dynamic Airspace Configuration |
| Enhanced Airborne Collision Avoidance for Commercial Air Transport Normal Operations | ACAS Xa is being designed for commercial aircraft to deliver the next generation traffic collision avoidance system (TCAS). By introducing additional surveillance data and optimised resolution advisories, ACAS Xa is expected to improve on today's system without changing the cockpit interface, i.e. using the same alerts and presentation. It forms part of ACAS X, a series of systems being developed for different users. Source: SESAR Joint Undertaking |

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| Enhanced Tactical Flow Management System | Enhanced version of the previous TACT system, which is a monitoring tool that supports decision making in short-term tactical actions. Source: EUROCONTROL |
| Essential Operational Change | The EOCs are the nine essential game changers triggering structural evolutions of the European ATM. They will be required to deliver the SESAR vision up to and including its Phase C, the defragmentation of European skies through virtualisation, and will enable the delivery of the SES objective of implementing more sustainable and better-performing aviation. Source: SESAR Joint Undertaking |
| Estimated Off-Block Time | The estimated time at which the aircraft will commence movement associated with departure. Source: SESAR |
| Estimated Take-Off Time | Forecast of time when aircraft will become airborne taking into account the EOBT plus EXOT. Source: SESAR |
| Estimated Taxi-Out Time | The estimated time between off-block and take off. This estimate includes any delay buffer time at the holding point or remote de-icing prior to take off. Source: EUROCONTROL |
| Estimated Time Over | Estimated entry time over airspace for a non-regulated flight based on flight plan data and Environment Database (ENV) data. Estimated time over a significant point. Source: EUROCONTROL |
| European Civil Aviation Conference | An intergovernmental organisation (44 Members States in 2010) active since 1955 in promoting the co-ordination, better utilisation and orderly development of European civil aviation in the economic, technical, security and safety fields. Source: EUROCONTROL |
| European Route Network Improvement Plan | The European Route Network Improvement Plan is a plan developed by the Network Manager in coordination with the operational stakeholders. It shall include the result of the Network Manager's operational activities with respect to route network design on short and medium terms following the guiding principles of the Network Strategy Plan. Source: EUROCONTROL |
| Executive Controller | The Executive Controller has responsibility for traffic management within the sector/AoR and the tactical tasks. They are responsible for the safe and expeditious flow of all flights operating within their area of responsibility. Their principal tasks are compliance with the ICAO Rules of the Air, other relevant ICAO (e.g. Doc. 4444) and European/National provisions to separate known flights operating within their area of responsibility and to issue instructions to pilots for conflict resolution and segregated airspace circumnavigation. Source: SESAR |
| eXplainable Artificial Intelligence | Explainable AI (XAI) refers to methods and techniques in the application of artificial intelligence technology (AI) such that the results of the solution can be understood by humans. It contrasts with the concept of the "black box" in machine learning where even their designers cannot explain why the AI arrived at a specific decision. Source: Ian Sample, The Guardian |
| Extended Flight Plan | The extended flight plan includes new information on the 4D trajectory, which contains additional elements for each point of the trajectory such as speed and aircraft mass, as well as flight-specific performance data, including predicted climb and descent profiles for a specific flight. Source: SESAR Joint Undertaking |
| Extended Projected Profile | Specifies the aircraft predicted trajectory up to 128 waypoints including for each waypoint, Latitude, Longitude and when available, Fix, Level, ETA, Airspeed, Vertical type(s), Lateral type(s), Level constraint, Time constraint, Speed |

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| | constraint. When available, provides the relevant data for the trajectory as Current gross mass and EPP trajectory intent status. It indicates the date and time these values were computed. Source: ICAO |
| Federal Aviation Administration | The Federal Aviation Administration (FAA), formerly the Federal Aviation Agency, was established by the Federal Aviation Act of 1958 (72 Stat. 731). The agency became a component of the Department of Transportation in 1967 according to the Department of Transportation Act (49 U.S.C. 106). The mission of the FAA is to regulate civil aviation and U.S. commercial space transportation, maintain and operate air traffic control and navigation systems for both civil and military aircraft, and develop and administer programs relating to aviation safety and the National Airspace System. Source: Federal Register |
| Flexible Use of Airspace | An ASM concept currently applied in the ECAC area and based on the fundamental principle that airspace should no longer be designated as either pure civil or military airspace, but rather be considered as one continuum in which all airspace user requirements have to be accommodated. Source: EUROCONTROL |
| Flight and Flow Information for a Collaborative Environment | A product of the ICAO Global ATM Concept, that defines information requirements for flight planning, flow management and trajectory management. Source: ICAO |
| Flight Information Exchange Model | A data interchange format for sharing information about flights throughout their lifecycle. Source: https://www.fixm.aero/ |
| Flight Information Region | An airspace of defined dimensions within which flight information service and alerting service are provided. Source: ICAO |
| Flight Management System | An integrated system, consisting of an airborne sensor, receiver and computer with both navigation and aircraft performance databases, which provides performance and RNAV guidance to a display and automatic flight control system. Source: ICAO |
| Flight Progress Strip | Electronic or paper strip containing the data from one specific flight plan, used in air traffic control for the display of flight data on a display screen or flight progress board. Source: EUROCONTROL |
| Flow Management Position | 1. A working position established in appropriate air traffic control units to ensure the necessary interface with a central management unit on matters concerning the provision of the air traffic flow management service. Source: ICAO<br>2. The interface between Air Traffic Control (ATC) and the Network Manager Operations Centre (NMOC) established in the States within, and adjacent to, the ECAC area. Source: EUROCONTROL |
| Free Route Airspace | Specific airspace within which users shall freely plan their routes between an entry point and an exit point without reference to the ATS route network. In this airspace, flights will remain subject to air traffic control. Source: EUROCONTROL |
| Functional Airspace Block | An airspace block based on operational requirements and established regardless of State boundaries, where the provision of air navigation services and related functions are performance-driven and optimised to introduce, in each functional airspace block, enhanced cooperation among air navigation service providers or, where appropriate, an integrated provider. Source: European Parliament, Council of the European Union |

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| High Frequency | High frequency (HF) is the ITU designation for the range of radiofrequency electromagnetic waves (radio waves) between 3 and 30 megahertz (MHz). It is also known as the decameter band or decameter wave as its wavelengths range from one to ten decameters (ten to one hundred metres). Source: Rec. ITU-R V.431-7, Nomenclature of the frequency and wavelength bands used in telecommunications |
| Human in the loop | Human-in-the-loop or HITL is defined as a model that requires human interaction. Source: Wikipedia |
| Human-machine interface | A feature or component of a certain device or software application that enables humans to engage and interact with machines. Source: EXOR |
| Identification Friend or Foe | Identification, friend or foe (IFF) is a radar-based identification system designed for command and control. It uses a transponder that listens for an interrogation signal and then sends a response that identifies the broadcaster. It enables military and civilian air traffic control interrogation systems to identify aircraft, vehicles or forces as friendly and to determine their bearing and range from the interrogator. IFF may be used by both military and civilian aircraft. IFF was first developed during World War II, with the arrival of radar, and several friendly fire incidents. Source: Joint Publication (JP) 3-09, Joint Fire Support |
| Indicated airspeed | The uncorrected reading on the airspeed indicator. Source: ICAO |
| Instrument flight rules | A set of rules governing the conduct of flight under instrument meteorological conditions. Source: ICAO |
| International Civil Aviation Organization | A specialized agency of the United Nations, ICAO was created in 1944 to promote the safe and orderly development of international civil aviation throughout the world. It sets standards and regulations necessary for aviation safety, security, efficiency and regularity, as well as for aviation environmental protection. The Organization serves as the forum for cooperation in all fields of civil aviation among its 188 Contracting States. Source: ICAO |
| Internet Protocol | The Internet Protocol is the principal communications protocol in the Internet protocol suite for relaying datagrams across network boundaries. Its routing function enables internetworking and essentially establishes the Internet. Source: Wikipedia |
| Key Performance Area | 1.A way of categorising performance subjects related to high-level ambitions and expectations. ICAO Global ATM Concept sets out these expectations in general terms. For SESAR, the 11 ICAO KPAs plus Human Performance (a proposed addition not yet formally adopted by ICAO) are considered as given. Source: SESAR<br>2.KPAs are a way of categorizing performance subjects related to high-level ambitions and expectations. Source: ICAO |
| Key Performance Indicator | A clearly defined measurement indicator considered to be of the highest importance for measurement in validation exercises and used for validation assessment. Source: SESAR |
| Knowledge graph | A knowledge graph is a programmatic way to model a knowledge domain with the help of subject-matter experts, data interlinking, and machine learning algorithms. Source: Julian Aijal, What is a knowledge graph and how does one work? |
| Letters of Agreement | Letters of agreement set out the high-level policy for cooperation between states under contingency conditions and can cover operational as well as technical |

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| | support. Letters of agreement provide ways of establishing mutual support under contingency. They enable planning well before an incident takes place. Testing and exercises can be used to determine whether or not states can implement the joint approaches described in letters of agreement. Source: EUROCONTROL |
| Loss of separation | A defined loss of separation between airborne aircraft occurs whenever specified separation minima in Controlled Airspace are breached. Minimum separation standards for airspace are specified by ATS authorities, based on ICAO standards. Source: SKYbrary |
| Machine learning | Machine learning is the science of getting computers to learn and act in the same way humans do, with improving their learning over time autonomously by being fed volumes of big data in the form of observations and real-world interaction. Source: Expert System (blog) |
| Maximum TakeOff Mass | The maximum takeoff mass (MTOM), often referred to as maximum takeoff weight (MTOW), of an aircraft is a value defined by the aircraft manufacturer. It is the maximum mass at which the aircraft is certified for take-off due to structural or other limits. MTOW is usually specified in units of kilograms or pounds. The mass is a fixed value and does not vary with changes in temperature, altitude or runway available. Source: SKYbrary |
| Medium-Term Conflict Detection | An integrated system of predictive tools performing the calculation of aircraft trajectories, the monitoring of an aircraft's progress against the trajectory, the detection of conflicting trajectories and the presentation of this information to the controllers up to 20 minutes ahead. Source: EUROCONTROL |
| Meteorological service for air navigation | A service that contributes to the safety, efficiency and regularity of air navigation. This is achieved by providing necessary meteorological information to operators, flight crew members, air traffic services units, search and rescue units, airport management and others concerned with aviation |
| Minimum Safe Altitude Warning | A ground-based safety net intended to warn the controller about an increased risk of controlled flight into terrain accidents by generating, in a timely manner, an alert of aircraft proximity to terrain or obstacles. Source: EUROCONTROL |
| Mitigating negative impacts of monitoring high levels of automation | A project aiming to develop solutions to mitigate the negative effect associated with the monitoring role of the human operators in automated systems, such as lack of attention, loss of situation awareness and skill degradation. Source: Cordis |
| Modern ATM via Human/Automation Learning Optimisation | The EU-funded MAHALO project aims to design an automated AI, ML and deep neuronal learning-based explainable system for problem-solving between aircrews and air traffic controllers. Trained by the individual operator, the machine will be able to inform the operator what it has learnt. This will increase capacity, performance and safety. Specifically, MAHALO will investigate the impact of transparency and conformity. The project will be evaluated in real-time simulations for traffic difficulties, trust, acceptance and controller understanding. MAHALO's framework will serve as a model for future AI systems. Source: Cordis |
| Multi Sector Planner | The role of a Multi Sector Planner is to offer a medium-level strategy rather than tactical solutions to overcome traffic complexity. Aircraft trajectories are planned over several sectors. The aim is to reduce the workload of sector controllers and provide more optimal trajectories for suitably equipped aircraft. |

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| | A Multi Sector Planner is responsible for the medium-term planning of the trajectories of the aircraft that enter the region of airspace, called a Multi-Sector Area (MSA), with which he is associated. Currently, this role does not exist in any operational ATC system. Source: EUROCONTROL |
| Multilateration | A group of equipment configured to provide position derived from the secondary surveillance radar (SSR) transponder signals (replies or squitters) primarily using time difference of arrival (TDOA) techniques. Additional information, including identification, can be extracted from the received signals. Source: ICAO |
| Natural Language Processing | Natural Language Processing, is a branch of artificial intelligence that deals with the interaction between computers and humans using the natural language.<br>The ultimate objective of NLP is to read, decipher, understand, and make sense of the human languages in a manner that is valuable.<br>Most NLP techniques rely on machine learning to derive meaning from human languages. Source: https://becominghuman.ai/a-simple-introduction-to-natural-language-processing-ea66a1747b32 |
| Nautical Mile | The length equal to 1 852 metres exactly. Source: ICAO |
| Network Operations Plan | A set of information and actions derived and reached collaboratively both relevant to, and serving as a reference for, the management of the Pan-European network in different timeframes for all ATM stakeholders, which includes, but is not limited to, targets, objectives, how to achieve them, anticipated impact. Source: SESAR |
| Non-Directional Radio Beacon | A low or medium radio navigation service transmitting signals whereby the pilot of a suitably equipped aircraft can determine bearings, 'home in' on, and/or track to or from the station. Source: Aeronautical Information Feature Data Dictionary (AIFDD) |
| Oceanic Area Control Centre | A part of the international airspace over oceanic regions where air traffic services are provided. |
| Operational Air Traffic | All flights, which do not comply with the provisions stated for GAT and for which rules and procedures have been specified by appropriate national authorities. Source: EUROCONTROL |
| Out-of-the-loop | The OOTL phenomenon corresponds to a lack of control loop involvement of the human operator. Automation technology is expected to create an increasing distance between ATCOs and the loop of control, making him disconnected from the automation system. Such removal could lead to a decreased ability of the ATCOs to intervene in system control loops and assume manual control when needed in overseeing automated systems. Source: Merat N., Jamson A. H.: How do drivers behave in a highly automated car? |
| Pilot in-command | The pilot in command (PIC) of an aircraft is the person aboard the aircraft who is ultimately responsible for its operation and safety during flight. Source: ICAO |
| Planning Controller | The Planning Controller is mainly responsible for planning and coordination of the traffic entering, exiting or existing within the ATC Sector. According to the company policy, local procedures, operating methods and traffic environment, the Planning Controller could endorse responsibilities belonging to different roles. Source: SESAR |
| Primary Surveillance Radar | A radar which detects the presence of a target based on reflected radar energy from that target. Source: EUROCONTROL |

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| Program for Harmonized ATM Research in EUROCONTROL | The Programme for Harmonised ATM Research in EUROCONTROL (PHARE) was a collaborative research programme within Europe to investigate a future Air Traffic Management (ATM) concept. The objective of PHARE was to organise, coordinate and conduct studies and experiments to demonstrate the feasibility and benefits of a future air-ground integrated air traffic management system in all phases of flight. Source: EUROCONTROL |
| Range and Bearing tool | A tool that allows ATCOs to measure range and bearing between any aircraft. It displays how far apart the aircraft are in terms of minutes. |
| Re-Categorisation | A re-categorisation of ICAO wake turbulence scheme and associated longitudinal separation minima on approach and departure. Source: EUROCONTROL |
| Reduced Vertical Separation Minimum | A reduction to 1000 feet vertical separation between flights, which is used in Europe and on the North Atlantic, between FL290 and FL410. Source: EUROCONTROL |
| Reference Business Trajectory | The trajectory that the Airspace User agrees to fly and that the ANSP and Airport agree to facilitate. Source: SESAR |
| Required Navigation Performance | Required Navigation Performance (RNP) is a family of navigation specifications under Performance Based Navigation (PBN) which permit the operation of aircraft along a precise flight path with a high level of accuracy and the ability to determine aircraft position with both accuracy and integrity. RNP offers safety benefits by means of its precision and accuracy and it reduces the cost of operational inefficiencies such as multiple step-down non-precision and circling approaches. Source: SKYbrary |
| Research and Development | Research and development (R&D) include activities that companies undertake to innovate and introduce new products and services. It is often the first stage in the development process. Source: Will Kenton, Investopedia |
| Route Adherence tool | The Route Adherence Monitoring function generates a flight alarm when an aircraft does not maneuver along a permitted route. Source: Seoung-Hyeon Lee, Conformance Monitoring Method based 4D Trajectory Modeling Using Aircraft Performance Data |
| Satellite Communication | Airborne radiotelephone communication via a satellite. Use of satellites for this purpose complements satellite-based navigation capability. Aircraft onboard equipment for SATCOM includes a satellite data unit, a high power amplifier and an antenna with a steerable beam. A typical aircraft SATCOM installation can support data link channels for ’packet data services’ as well as voice channels. SATCOM data link is currently used for only a small proportion of en route ATM communications in contrast to the much more extensive use as an alternative to VHF and HF for non-ATC purposes. Source: SKYbrary |
| Secondary Surveillance Radar | A surveillance radar system which uses transmitters/receivers (interrogators) and transponders. Source: ICAO |
| Segregated Area Probe | A tool that lists warnings/conflicts for ATCOs in case of segregated areas in their sector. |
| Separation display tool | A tool that displays the minimum separation distance of aircraft and how long it will take for them to reach that distance. It is only available for aircraft with converging tracks. |

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| Short Term Conflict Alert | A ground-based safety net intended to assist the controller in preventing collision between aircraft by generating, in a timely manner, an alert of a potential or actual infringement of separation minima. Source: EUROCONTROL |
| Single European Sky | The initiative launched by the European Commission in 2004 to reform the architecture of European air traffic management. It proposes a legislative approach to meet future capacity and safety needs at a European rather than a local level. Source: SESARJU |
| Situation Awareness Global Assessment Technique | The Situation Awareness Global Assessment Technique is a query technique that was developed by Endsley. SAGAT is based on information-processing theory. Endsley considers situation awareness as an internal model that is derived from the environment prior to decision-making and performance. SAGAT is one of the best publicized and most widely known measure of SA. Source: EUROCONTROL |
| Situation Awareness Rating Technique | The situation awareness rating technique (SART) is a simplistic post-trial subjective rating technique that was originally developed for the assessment of pilot SA. SART uses the following ten dimensions to measure operator SA: Familiarity of the situation, focussing of attention, information quantity, information quality, instability of the situation, concentration of attention, complexity of the situation, variability of the situation, arousal, and spare mental capacity. Source: EUROCONTROL |
| Situation Present Assessment Method | SPAM is a method of measuring situation awareness (SA). The Situation Present Assessment Method is based on the assumption that SA may sometimes involve simply knowing where in the environment to find some information, rather than remembering what that information is exactly. In contrast to SAGAT, the SPAM method uses response latency as the primary dependent variable and does not require a memory component. Source: EUROCONTROL |
| Situational Awareness | SA is the perception of environmental elements and events with respect to time or space, the comprehension of their meaning, and the projection of their future status. Source: Mica R. Endsley, Toward a theory of situation awareness in dynamic systems |
| Special VFR | A VFR flight cleared by air traffic control to operate within a control zone in meteorological conditions below visual meteorological conditions. Source: ICAO |
| System-wide information management | 1) [SWIM consists of] standards, infrastructure and governance enabling the management of ATM information and its exchange between qualified parties via interoperable services. Source: ICAO<br>2) A distributed processing environment which replaces data-level interoperability and closely coupled interfaces with an open, flexible, modular and secure data architecture transparent to users and their applications. Source: SESAR |
| Tactical Controller Tool | Tactical Controller Tool (TCT), operating in both En-Route and TMA, warns the executive (tactical) controller of potential conflicts within the sector. To do this it usually combines current aircraft tracks with an accurate tactical trajectory that reflects the aircraft's current behaviour. Some implementations are based only on surveillance data (assuming the aircraft will maintain their tracks, speeds and levels). TCT is primarily a separation assurance aid. It aims to reduce workload per aircraft for the executive (tactical) controller by providing very accurate monitoring and conflict detection. TCT helps not only in detecting problems but also in showing that no problems exist. Source: EUROCONTROL |

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| Tactical Load Smoother | The Tactical Load Smoother (TLS) is a tool that was developed to support the multi-sector planner in their work. Its purpose is to analyse future traffic, taking into account a number of parameters including prediction uncertainty, and to produce an indication of when and where conditions are likely to become excessively difficult for sector-level controllers. Source: EUROCONTROL |
| Team | A team is a group of RE, RP, automation and AI working together to achieve the shared SA, etc. |
| Terminal Control Area | A terminal control area is a Control Area normally established at the confluence of ATS routes in the vicinity of one or more major aerodromes. Source: ICAO |
| Time-Based Separation | Time Based Separation replaces current distance separations with time intervals in order to adapt to weather conditions. It provides consistent time-based spacing between arriving aircraft in order to maintain runway approach capacity.The TBS software uses real-time information about the weather, airspeed, ground speed, heading and altitude to display time-based separation and arrival speed information to the approach controller. Source: SESARJU |
| Towards an Automated and exPlainable ATM System | TAPAS aims at exploring highly automated AI-based scenarios through analysis and experimental activities applying eXplainable Artificial Intelligence (XAI) and Visual Analytics, to derive general principles of transparency which pave the way for the application of these AI technologies in ATM environments, enabling higher levels of automation. Source: CORDIS |
| Traffic Complexity Management | Air traffic complexity is often defined as the difficulty of controlling a traffic situation, and it is, therefore, one of the drivers for the air traffic controller's workload. With more workload, the probability of air traffic controller committing an error increases, so it is necessary to be able to assess and manage air traffic complexity. Source: Tomislav Radišić et al., Air Traffic Complexity as a Source of Risk in ATM |
| Trajectory Prediction Improvement | The Traffic Prediction Improvements (TPI) tool calculates the route an aircraft is most likely to fly, not by looking at the filed flight plan, but by looking at historical flight data. Source: EUROCONTROL |
| Ultra-high frequency | Ultra-high frequency is the ITU designation for radio frequencies in the range between 300 megahertz and 3 gigahertz, also known as the decimetre band as the wavelengths range from one meter to one-tenth of a meter. Source: Nomenclature of the frequency and wavelength bands used in telecommunications |
| Very high frequency | Very high frequency is the ITU designation for the range of radiofrequency electromagnetic waves from 30 to 300 megahertz, with corresponding wavelengths of ten meters to one meter. Source: Nomenclature of the frequency and wavelength bands used in telecommunications |
| Very High-Frequency Omnidirectional Radio Range | VHF Omnidirectional Radio Range (VOR), is an aircraft navigation system operating in the VHF band. VORs broadcast a VHF radio composite signal including the station's Morse Code identifier (and sometimes a voice identifier), and data that allows the airborne receiving equipment to derive the magnetic bearing from the station to the aircraft. This line of position is called the "radial". Source: SKYbrary |
| Vigilance and Attention Controller | A system based on electroencephalography (EEG) and eye-tracking (ET) techniques, aimed to assess in real-time the vigilance level of an ATCO dealing with a highly automated human-machine interface and to use this measure to |

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| | adapt the level of automation of the interface itself. Source: Gianluca Di Flumeri et al., Brain–Computer Interface-Based Adaptive Automation to Prevent Out-Of-The-Loop Phenomenon in Air Traffic Controllers Dealing With Highly Automated Systems |
| Visual Flight Rules | A set of rules governing the conduct of flight under visual meteorological conditions. Source: ICAO |
| Visual Meteorological Conditions | Meteorological conditions expressed in terms of visibility, distance from cloud, and ceiling, equal to or better than specified minima. Source: ICAO |

**Table 2 Table of definitions**

# Appendix B En-Route Air Traffic Control

## List of Figures



## List of tables

## B.1 Area of jurisdiction

According to the International Civil Aviation Organization (ICAO) Doc 4444 [4], Area Control Centre (ACC) is a unit founded to provide air traffic control service to controlled flights in control areas that are under its authority.

En-Route Control provides separation between aircraft that are operating in a controlled or advisory airspace. They do this in accordance with the airspace classification and aircraft flight rules, as well as issue Air Traffic Control (ATC) clearances to aircraft. En-Route Control sometimes provides ATS in airspace that is ordinarily the province of another control unit and can do so on a permanent or limited basis.

An Area Control Center is established in each Flight Information Region (FIR) to provide its services in the airspace under its jurisdiction. En-Route Control Services are also provided at:

- Oceanic Area Control Centres (OAC)
- ATC units at aerodromes that are specified by the Civil Aviation Authority (CAA).

The type of service En-Route Control provides depends on the class of airspace and flight rules explained in Table 1 [5].

| Class | Flight Rules | Aircraft Requirements | Minimum Services by ATC Unit |
|---|---|---|---|
| A | Instrument flight rules (IFR) only | ATC clearance before entry. Comply with ATC instructions. | Separate all aircraft from each other. |
| B | IFR and Visual flight rules (VFR) | ATC clearance before entry. Comply with ATC instructions. | Separate all aircraft from each other. |
| C | IFR and VFR | ATC clearance before entry. Comply with ATC instructions. | **a)** Separate IFR flights from other IFR and VFR flights;<br><br>**b)** Separate VFR flights from IFR flights;<br><br>**c)** Pass traffic information to VFR flights on other VFR flights and give traffic avoidance advice if requested |
| D | IFR and VFR | ATC clearance before entry. Comply with ATC instructions. | |
| E | IFR and VFR | IFR flights to obtain ATC clearance before entry and comply with ATC instructions.<br><br>VFR flights do not require clearance. | |

| | | | |
|---|---|---|---|
| F | IFR and VFR | Participating IFR flights are expected to comply with ATC instructions. | |
| G | IFR and VFR | None | |

**Table 1 Classification of Airspace [4]**

## B.2 Principles of operation

An ACC consists of several sectors and they all cooperate closely. The method of operation is different at each centre but it is always based on the same principles:

- controllers are responsible for the efficient performance only of those tasks that are specifically assigned in their task description;
- controllers must monitor the actions of other members of their sector team, but only to the extent their prime duties permit;
- all sectors must have a display that allows them to detect a conflict, and that display should reflect all issued clearance instructions and received communications;
- purposes of co-ordination between sectors require some criteria which enable the co-ordinator (when such thing is authorized by the CAA) to use information obtained by surveillance in order to transfer traffic between sectors without referencing the controller [5].

## B.3 Route network and FRA

According to ICAO Annex 11 [47], an ATS route is a specified route that is designed to channel the flow of traffic in the way it is necessary for the provision of ATS. An ATS route can mean a number of things: an airway, an advisory route, a controlled route, an uncontrolled route, an arrival route, a departure route, and so on. ATS routes are defined by the specifications of the route including: a designator, the track to or from waypoints, distance between significant points, some reporting requirements, and the lowest safe altitude. Even though still most commonly used, route network might soon be a thing of the past considering numerous new advances regarding safe, efficient, and environmentally friendly air traffic.

Free Route Airspace (FRA), is a relatively new concept that is already starting to catch on in the aviation community. The European Route Network Improvement Plan (ERNIP) [48] describes it as a specified airspace where users can freely plan a route between defined entry and exit points (Figure 1). Naturally, flights still remain subject to ATC within FRA. There are numerous advantages to being able to freely plan a route between defined entry and exit points, which help to reach Europe-wide performance targets such as horizontal en-route flight efficiency (the difference between flight flown and the corresponding great circle distance). According to EUROCONTROL [49], once FRA is fully implemented at a European level, it should allow for significant savings which, in comparison to the current situation, correspond to these numbers: 500000 NM/day, 3000 tonnes of fuel/day, 10000 fewer $CO_2$ tonnes/day and € 3 million in fuel costs savings/day. Those are all impressive numbers, however, FRA isn't the only concept that is making an impact. Functional Airspace Blocks (FABs) and the Flexible Use of Airspace (FUA) also brought numerous benefits. They helped connect the European sky and reduce the previously required amount of coordination between countries regarding route planning. However, the implementation of new concepts may not always be easy or practical. Not all countries have the same resources allowing them to implement in time, nor the system readiness on the country level. Sometimes it is even impractical to make those changes, for example, a FRA in a country with a lot of military activity. However, according to the Commission Implementing Regulation No 716/2014 [38], it will be mandatory to implement FRA as of 1st January 2022.

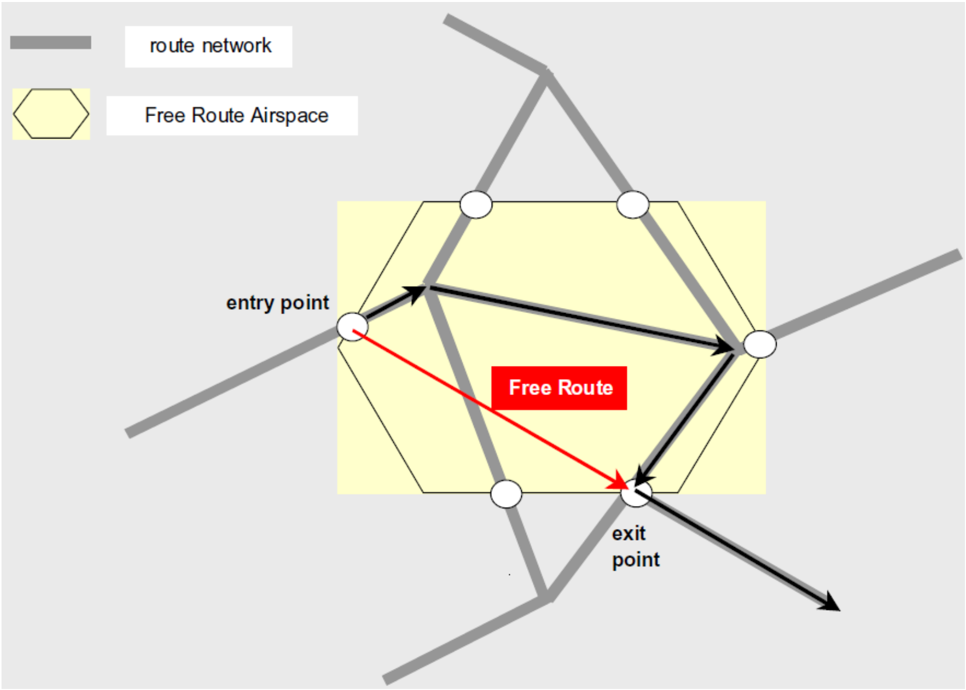


Figure 1 FRA concept [49]

## B.4 Rules and separation methods

Different separation standards allow aircraft to safely navigate in controlled airspace. They ensure safe separation between aircraft, from the ground, and various protected areas of airspace. National separation standards get their bases from ICAO Doc 4444 and if they differ from these standards, then those deviations are published in national Aeronautical Information Publications (AIPs). There are different methods Air Traffic Control Officers (ATCOs) use to achieve separation, some more complex than others, and they depend on the aircraft's phase of flight and its relative trajectories. The separation methods listed below are some of the simpler methods used in en-route air traffic control.

### B.4.1 Rules of the air

When talking about air traffic, we can separate flights into those flying by IFR rules and those flying by VFR rules. VFR flights are conducted in conditions of sufficient visibility. The necessary visibility is determined by distance from clouds that is equal or greater than the one prescribed in Table 2 (for clarification on airspace classes see Table 1).

| Altitude band | Airspace class | Flight visibility | Distance from cloud |
|---|---|---|---|
| At and above 10000 ft Above Mean Sea Level (AMSL) | A1 B C D E F G | 8 km | 5000 ft horizontally and 1000 ft vertically |
| Below 10000 ft AMSL and above 3000 ft AMSL, or above 1000 ft above terrain (whichever is the higher) | A1 B C D E F G | 5 km | 5000 ft horizontally and 1000 ft vertically |
| At and below 3000 ft AMSL, or 1000 ft above terrain (whichever is the higher) | A1 B C D E | 5 km | 5000 ft horizontally and 1000 ft vertically |
| | F G | 52 km | Clear of cloud and with the surface in sight |

**Table 2 Visual Meteorological Conditions (VMC) Visibility/Distance from cloud minima [50]**

Some notes ought to be mentioned: when the transition altitude is lower than 10000 ft AMSL, FL100 is used instead of 10000 ft.

[1] The visual meteorological conditions (VMC) minima in class A airspace does not mean VFR flights are accepted in its airspace.

[2] When the competent authority prescribes so, flight visibility can be reduced but not less than 5000 ft is permitted for flights operating:

- at 140 kts or less of indicated airspeed (IAS) for them to observe other traffic or any other obstacles in time to avoid a collision; or
- when encounter probability with other traffic is usually low (such as low volume traffic areas and aerial work at low levels).

When meteorological conditions drop below VMC, air traffic control can still clear a VFR flight and allow it to operate within a controlled area. Such VFR flights are called Special VFR (SVFR) and they entail several additional conditions:

- they can be conducted only during the day unless a competent authority permits otherwise;
- the pilot has to stay clear of clouds and have the surface in sight; flight visibility cannot be less than 5000 ft; aircraft's speed has to be 140 kts IAS or less;
- when meteorological conditions at an aerodrome fall below the minima (ground visibility is less than 5000 ft and/or the ceiling is less than 600 ft), the ATC unit cannot issue a special VFR clearance for the aircraft that needs to take off or land at such an aerodrome in a control zone or even enter the aerodrome traffic zone or an aerodrome traffic circuit.

IFR flights are a completely different story as they are reliant on their instruments instead of the current visibility. Aircraft flying IFR need to have suitable instruments and navigation equipment that is appropriate to their route and complies with the relevant legislation. Their minimum flight altitudes also differ from VFR requirements, although they can be reduced by the appropriate authorities. For high terrain or mountainous areas, the minimum is at least 2000 ft above the highest obstacle that is located within 8 km of the aircraft's position. The minimum elsewhere is at least 1000 ft above the highest obstacle that is located within 8 km of the aircraft's position. It is also possible to change from an IFR flight to a VFR one. When doing so, the pilot must say that they are cancelling the IFR flight and communicate further changes in the flight plan. However, a pilot will not simply switch from IFR to VFR if VMC is encountered during the flight unless of course it is anticipated and intended. ATS is not in charge of suggesting the change from an IFR flight to a VFR flight, but can only accept it when the pilot-in-command (PiC) specifically says „cancelling my IFR flight“ and in doing so provides changes made to the flight plan, if there are any [50].

To better understand the following subsections, some basic types of tracks should be explained: same, reciprocal, and crossing tracks. The same tracks, as the name implies, go in the same direction. They can also intersect at an angular difference of less than 45° or more than 315° which is better described in Figure 2.

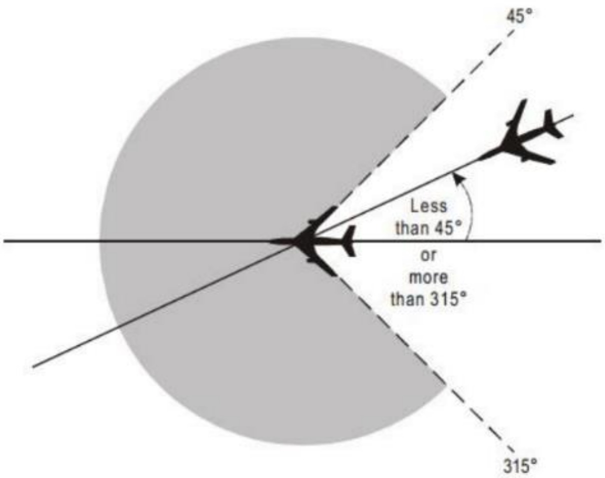


**Figure 2 Same tracks [51]**

Reciprocal tracks refer to tracks coming from opposite directions. They can also be intersecting tracks if their angular difference is more than 135° or less than 225° as imaged below in Figure 3.

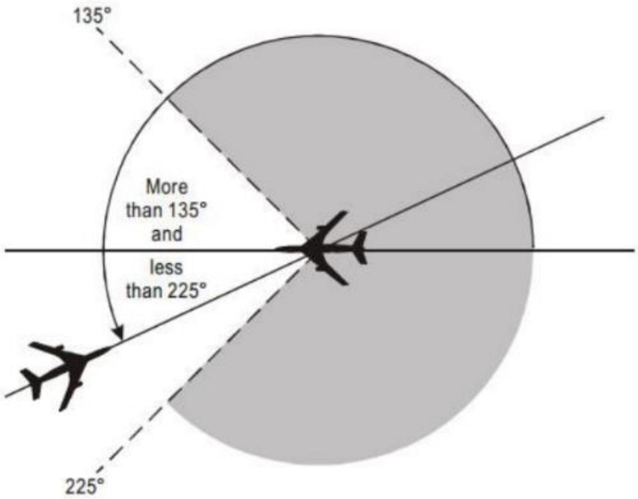


**Figure 3 Reciprocal tracks [51]**

And finally, there are crossing tracks which are intersecting tracks in all other conditions besides already mentioned same and reciprocal tracks. To further elaborate, those are tracks of an angular difference of more than 45° or less than 135°, and more than 225° and less than 315° [51]. Figure 4 represents the listed conditions.

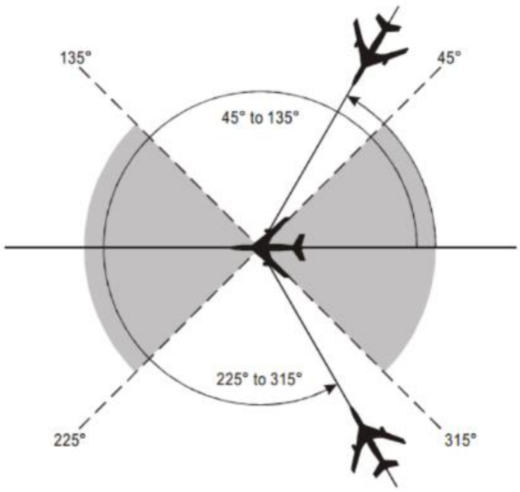


**Figure 4 Crossing tracks [51]**

## B.4.2 Vertical Separation

Vertical separation is achieved when aircraft in close proximity operate at different levels (altitude or flight level). Aircraft are required to use a prescribed altimeter pressure setting to achieve accurate readings. Minimum vertical separation, according to ICAO, is 2000 ft (600 m) for IFR flights that are above FL290 ft and up to FL410. In some airspaces, however, Reduced Vertical Separation Minimum (RVSM) is implemented, reducing the vertical separation minima between FL290 and FL410 from 2000 ft to 1000 ft. These rules are valid in most national authorities, however a different level at which the rule changes could be specified [4]. This type of separation is normally used when aircraft are on crossing paths or have to fly a certain portion of their path in the same direction, yet they are less than 5 NM apart horizontally. When that is the case and an ATCO is not sure they will manage to climb/descend in time, they may issue a rate of climb/descent as a means to speed up their separation.

### B.4.3 Lateral Separation

Lateral separation can be achieved with different methods, some of which will be listed below.

ATCOs can request pilots to report their positions when they are overflying different geographic locations, as can be seen in Figure 5, to track them and separate them easily.

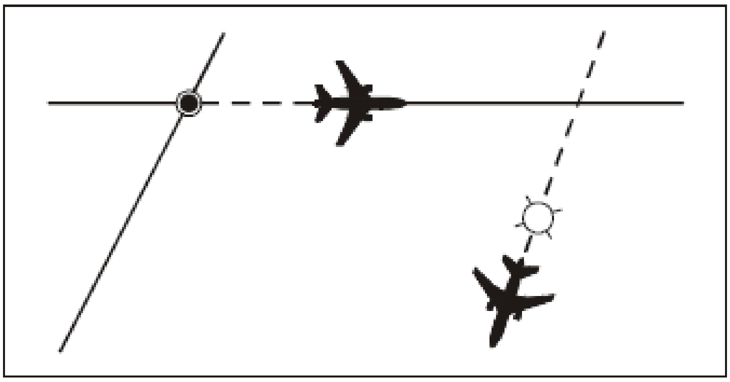

**Figure 5 Lateral separation in reference to different geographic locations [4]**

Aircraft can also be required to fly on certain tracks that are separated by a minimum angle. Such aircraft must be on diverging radials or tracks, depending on the type of navigation aid that is in use. At least one aircraft must be distanced at least 15 NM from the facility to ensure the accuracy and appropriate distance separation (Figures 6 and 7) [4].

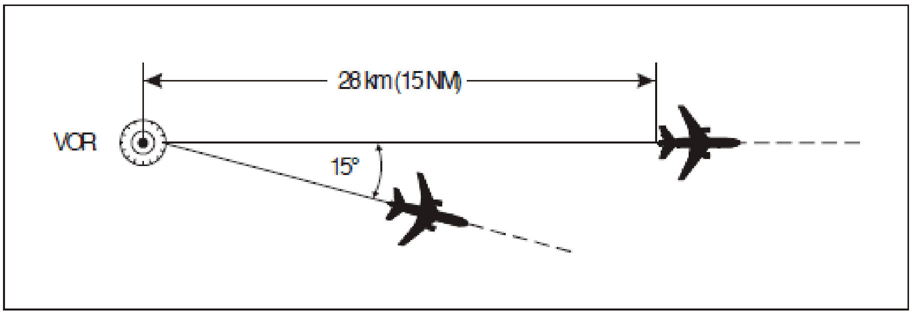


**Figure 6 Lateral separation in reference to Very High Frequency (VHF) Omni-Directional Range (VOR) [4]**

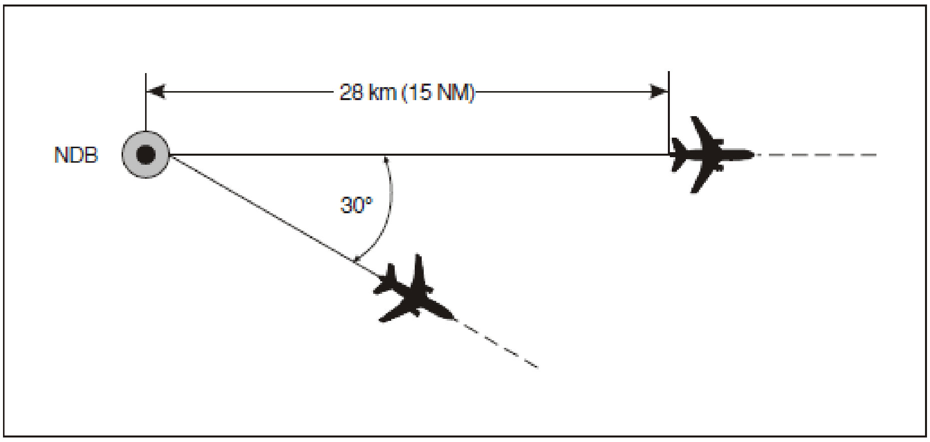


**Figure 7 Lateral separation in reference to Non-Directional Beacon (NDB) [4]**

### B.4.4 Longitudinal Separation

Longitudinal separation refers to the spacing between succeeding aircraft that is never less than a specified minimum. For aircraft that are on the same or diverging tracks, longitudinal separation can be achieved by position reports from aircraft and the time comparison of their reports or by speed control (as shown in Figure 8). The speed of the succeeding aircraft should not exceed the speed of the leading aircraft, however, it can be the same if there is already enough distance between them. Reduced separation can also be applied if the leading aircraft is maintaining a higher speed than the following aircraft. This is called a Mach Number Technique and is described in ICAO Doc 4444 [4]. For example, a leading aircraft is given Mach number 0.46 or greater and the succeeding one needs to fly 0.46 or less. This technique is further elaborated in Table 3. Separation by speed is very important when succeeding aircraft are leaving an ATCOs area of responsibility and entering another area of responsibility. That way aircraft are not allowed to change their speed during handover, thus remaining appropriately separated. Letters of Agreement (LoA) between countries prescribe rules for such situations and should be consulted.

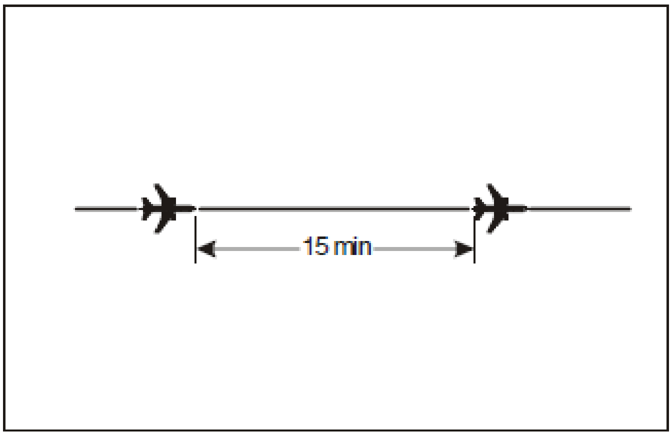


**Figure 8 Longitudinal separation [4]**

| Difference in Mach | Distance to fly and separation (in minutes) in Mach required at entry | | | | |
|---|---|---|---|---|---|
| | 1-600 NM | 601-1200 NM | 1201-1800 NM | 1801-2400 NM | 2401-3000 NM |
| .01 | 1 | 2 | 3 | 4 | 5 |
| .02 | 2 | 4 | 6 | 8 | 10 |
| .03 | 3 | 6 | 9 | 12 | 15 |
| .04 | 4 | 8 | 12 | 16 | 20 |
| .05 | 5 | 10 | 15 | 20 | 25 |
| .06 | 6 | 12 | 18 | 24 | 30 |
| .07 | 7 | 14 | 21 | 28 | 35 |
| .08 | 8 | 16 | 24 | 32 | 40 |
| .09 | 9 | 18 | 27 | 36 | 45 |
| .10 | 10 | 20 | 30 | 40 | 50 |

**Table 3 Mach number technique [52]**

### B.4.5 Separation minima based on ATS surveillance systems

Minimum separation prescribed by ICAO Doc 4444 [4] when there are surveillance systems in use is 5 NM (unless the relevant ATS authority states otherwise). This minimum can be reduced even further by the appropriate ATS authority but it can never be below 3 NM when surveillance capabilities permit this, or 2.5 NM between succeeding aircraft that are on the same final approach and within 10 NM of the runway threshold. The appropriate ATS authority also prescribes its separation minimum or minima based on the equipment being used - radar, Automatic Dependent Surveillance-Broadcast (ADS-B), and/or Multilateration (MLAT) systems. Separation minima can also be higher than 5 NM horizontally if necessary in certain parts of the airspace and/or at certain times.

### B.4.6 Wake Vortex Turbulence

More restrictive separation minima also exists in order to ensure that following aircraft (especially smaller ones) are not in a hazardous situation created by the wake vortex turbulence of the preceding aircraft. ICAO categorises aircraft based on their Maximum TakeOff Mass (MTOM), then minimum separation is determined, based on time or distance, and applied to aircraft flying in sequence. Aircraft that are following a higher MTOM aircraft get more spacing than aircraft following the same or lower MTOM category [4]. Table 4 describes the mentioned criteria.

| Preceding Aircraft | Following Aircraft | Minimum Separation |
|---|---|---|
| HEAVY | HEAVY | 4 NM |
| HEAVY | MEDIUM | 5 NM |
| HEAVY | LIGHT | 6 NM |
| MEDIUM | LIGHT | 5 NM |

**Table 4 Separation criteria [4]**

This separation criteria are applicable when:

- two aircraft fly on the same altitude one behind the other or less than 1000 ft above/under each other
- when two aircraft use the same runway or parallel runways that are less than 2500 ft apart
- when two aircraft cross paths on the same altitude, or are less than 1000 ft above/under each other.

A newer classification also exists which is not solely based on the aircraft's weight on which ICAO wake vortex separation rules are based. While the classic rules still apply, they are now considered outdated and can produce over-separation which causes unnecessary traffic delays thus increasing fuel burn, costs and emissions. Other aircraft characteristics also affect the following aircraft's reaction to the wake and the strength of the vortex, such as speed and wingspan. That's why a new categorisation has been made [53]:

| Category | Type |
|---|---|
| CAT A | Super Heavy |
| CAT B | Upper Heavy |
| CAT C | Lower Heavy |
| CAT D | Upper Medium |
| CAT E | Lower Medium |
| CAT F | Light |

**Table 5 New categorisation [53]**

### B.4.7 Emergency separation

It is sometimes not possible to ensure that horizontal separation is going to be maintained during an emergency, which means it is allowed to use half of the relevant vertical separation minimum during such situations. Meaning that a 1000 ft vertical separation minimum should be reduced to 500 ft, a 2000 ft vertical separation minimum to 1000 ft, and so on. If emergency separation is used all flight crews concerned must be informed in order to maintain safe air traffic flow even in such situations [4].

### B.4.8 Separation by coordination

Another way of separation can be acquired through coordination with other ATCOs, regardless of their working position – they can be working on a different sector or a neighbouring country. As a certain flight progresses, ATC units responsible for the flight forward the necessary flight plan and control information from one unit to another. There is an agreement between ATS authorities to help maintain the aircraft separation when it is so required. When there are flights along specified routes or portions of routes that are close to boundaries of FIRs, then it is also important to provide a flight plan and flight progress information to the ATC units in charge of the FIRs that are adjacent to such routes or portions of routes. The mentioned routes, or portions thereof, are referred to as an area of common interest since they are usually determined by the required separation minima [4]. Coordination between ATCOs internally (planner and executive, or ATCOs working on different sectors) is done verbally or via electronic coordination tools. Unfortunately, external coordination is still achieved by telephone which takes a lot of the planner's time.

### B.4.9 Modes of operation

To better understand the way ATCOs operate, it is important to list out some of their main tasks: maintaining SA, construct sector control plans and revise them, resolve aircraft conflict and reroute them, manage arrivals, departures, and overflights, receive and initiate handoffs and receive pointouts [54]. A simpler schematic of controller activities has been developed in 1996 and is shown in Figure 9.

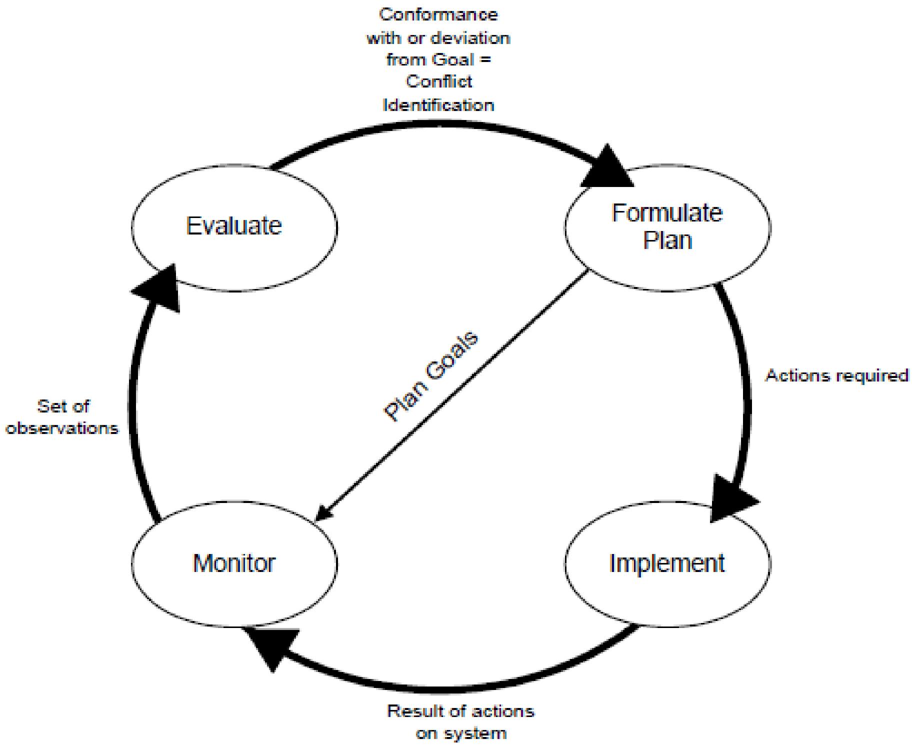


**Figure 9 ATC processes [54]**

Different factors influence an ATCOs performance in the execution of previously mentioned tasks. Factors such as time pressure, noise, stress, and distraction. Even though the workload is subjective, it offers a distinction between itself and the objectiveness of the task load [54]. ATC tasks can also be divided into only three main areas: routine tasks, tasks involving level change, and conflict tasks. Each of them contains several other tasks the controller has to accomplish. Conflict tasks can be expanded into identification and resolution tasks, as well as monitoring of conflicts [55].

In another attempt to divide tasks into categories, they can also be split into the following categories: procedural tasks, continuous tasks, reactive tasks, information acquisition, and processing tasks. Procedural tasks are those that take place only once for each aircraft. Such tasks are done in a specific order as the aircraft transits the airspace. Continuous tasks take place continuously without being interrupted by other tasks. They fall under key controlling tasks like conflict searching and conformance monitoring. Reactive tasks are not under the control of an ATCO, but rather coordinations coming from adjacent sectors, safety nets, and other system alerts. As the name implies, they only happen when certain triggers activate them. Information acquisition and processing tasks are sub-tasks of the above-mentioned tasks [12].

Lastly, when discussing modes of operation, it is important to note the different roles ATCOs occupy during their workday. Each working position consists of a single planner controller (PLC) and an executive controller (EXE). The main responsibilities of a planner are the coordinations outside the sector, meaning the organization of air traffic with adjacent sectors and neighbouring countries. Planners are not responsible for communication with pilots as that is the executive's job. EXE controllers identify aircraft, communicate with pilots, issue clearances, and overall perform all tasks we link to air traffic controllers. In the future, there might be more members in an ATCO team, but that is something further discussed in the following sections of this ConOps.

## B.5 System of monitoring the air traffic

To monitor aircraft and their height-keeping performance, specialized systems are used that collect necessary data using estimations of relevant performance parameters and comparison of these parameters in relation to RVSM requirements. This is done on both an individual-aircraft level and a system-wide basis.

There are two monitoring objectives in air traffic:

- insurance of the height-keeping performance in RVSM airspace conforms with system requirements that support the continued safe use of the RVSM and
- the insurance that individual operators and aircraft are going to adhere to RVSM requirements [56].

### B.5.1 Primary and secondary radar

Main monitoring tools in the air traffic industry are primary and secondary radar. A primary surveillance radar (PSR) works on the principle of a radar pulse which is transmitted from the ground-based antenna and then listens for the answer in the shape of returned energy reflected from an aircraft. By doing so, a measure of the range is obtained through a simple calculation of the time delay between the transmission of the pulse and its reflected return. The application of the radar in ATC was started after its rapid wartime development (after World War 2). Not only did this mean continuous surveillance of air traffic, independent from the radio position reports, but it also reduced the procedural separation standards since it offered such an increased precision. Although it offers an indication of the whereabouts of the aircraft, its flaw is the inability to positively identify each one.

The secondary surveillance radar (SSR) was also a byproduct of wartime considering PSR faults – huge amounts of power radiated that were needed to ensure returns from the target, a small amount of energy that was returned at the receiver that can be easily disrupted, and additional identification process for each aircraft. That is why the SSR relies on a transponder, a radio receiver, and a transmitter that operates on the radar frequency. The transponder on the aircraft responds to ground station interrogation in a way that it transmits a coded reply signal. The distinction between a friendly and enemy aircraft during wartime was based on the Identification Friend or Foe (IFF) system, something it is still based on. SSR can detect and identify aircraft as well as provide the Flight Level (its altitude based on pressure) of an aircraft. The SSR brought in quite a few advantages to ATC surveillance. The reply signal is much stronger when it is received at the ground station, meaning greater range and fewer problems with the signal attenuation. The required transmitting power of the ground station is reduced providing a considerable economy, and not to mention the new possibility of transmitting additional information between the two stations [6].

The radar vectoring procedure is one of the tools used by ATCOs in areas where ATC service is provided. Basic methods of radar vectoring constitute of several rules in order to handle all aircraft and optimize the use of airspace. Vectoring is achieved by issuing headings to the pilot for the aircraft to follow the intended track. The ATCO should comply with the following rules when vectoring an aircraft:

- an aircraft is to be vectored along tracks with reference to navigational aids to minimize the required navigational assistance in case of ATC surveillance system failure
- the pilot is to be informed of the vector and its limits when it diverts from their route
- aircraft are not to be vectored closer than 2.5 NM, or if the minimum separation is greater than 5 NM half of the minimum prescribed (except when a transfer of control is going to be effected or there are local arrangements that ensure the separation)
- controlled flights are not to be vectored into uncontrolled airspace (only in cases of emergency, to avoid meteorological conditions or at pilot's request)
- in the case of unreliable directional instruments, it is to be agreed with the pilot to make all turns at an acknowledged rate and immediately upon receipt of manoeuvring instructions [4].

Vectoring is normally used for traffic management, sequencing, separation, and conflict prevention. When terminating aircraft vectoring, the pilot is to be instructed to resume own navigation.

## B.5.2 Automatic Dependent Surveillance

When satellite technology became available, other types of ATC surveillance equipment became a possibility. This meant radar coverage in areas where it does not or cannot exist. The name Automatic Dependent Surveillance (ADS) comes from no pilot or ATCO input for it to function (thus Automatic), and Dependent because it still needs operating airborne equipment (much like the SSR). It is a datalink system transmitting data from the aircraft (data such as altitude, position, and intended flight path) to the ground system. The ADS-C system (ADS-Contract) is the original one and was named that way because it gave reports from the aircraft that were generated in conformance with a so-called contract that was set up with the ground system. They are used instead of pilot verbal reports and allow procedural separation. An ADS-Broadcast (ADS-B) is a further applicationof ADS where the aircraft has a transponder broadcasting at a much greater rate than ADS-C (twice per second). Such information can be received by a ground station, ATS, or by another aircraft [6].

## B.6 Means of support

Many methods have been developed throughout the years regarding separation between aircraft and humans were essential because of their ability to combine various information into meaningful data and make judgments based on obtained data. Since failures and operational errors can still occur due to human error, automated systems are starting to appear more often in the cockpit and on the ground. These systems provide support during the decision-making process and serve as traffic conflict alerting systems [57].

### B.6.1 Separation tools

QDM (Range and Bearing tool) and SEP (Separation display tool) are both tools often used by ATCOs. QDM measurement vector allows them to measure range and bearing between any aircraft while also displaying how far apart they are in terms of minutes which helps the ATCOs with separating them. The range and bearing measurements can also be done between two fixed points, or between a point and an aircraft. SEP is also a separating tool often used for horizontal separation of aircraft which displays the minimum separation distance of aircraft and how long will it take for them to reach that distance. It is only available for aircraft with converging tracks and will produce an alert if necessary.

A Probe tool, also called a what-if tool, allows the controller to test whether a planned clearance will cause conflict without actually making any changes to the flight. When Probe is used before a clearance, it shows a temporary trajectory and potential conflicts should the controller decide to issue the clearance.

MTCD (Medium-Term Conflict Detection) is an extension of the Short Term Conflict Alert (STCA) concept and is designed to warn the controller about potential conflicts between flights in their area of responsibility up to 20 minutes before they occur. MTCD has several functions: trajectory prediction, conflict detection, trajectory update, and edition. These functions allow it to detect and notify the controller of probable loss of separation between two aircraft, of aircraft penetrating segregated or restricted airspace and of aircraft-to-aircraft encounters in which certain aircraft is blocking airspace that could be used by another aircraft (even though the required separation is achieved) [7]. The context of MTCD is depicted in Figure 10 below.

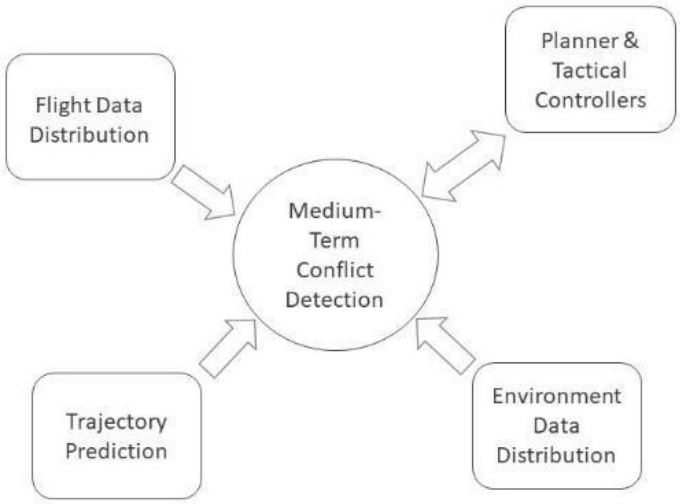


**Figure 10 MTCD context [7]**

Another result of the same program within which MTCD was developed, yielded the Tactical Controller Tool (TCT). As opposed to MTCD, it is used as a short term conflict detection tool (it warns the ATCO 5-8 minutes ahead) and a clearance verification tool. TCT is considered one of the most helpful tools for an executive ATCO as it is used both in en-route and TMA and warns the executive controller of potential conflicts within their sector. Another helpful indicator of the tool is a critical missed manoeuvre, where the loss of separation will occur if an aircraft fails to make a planned manoeuvre [8].

Downlinked Aircraft Parameters (DAPs) feed information from the aircraft flight management system (FMS) and enhance some basic functions. It provides enhanced trajectory prediction, better quality of the Flight Path Monitoring (FPM) tool, improved situational awareness (SA), improved guidance, and reduced voice communication requirements thus reducing workload and potentially increasing capacity and enhanced intent information regarding surveillance. However, to be implemented it requires an aircraft to be equipped with relevant technology as well as an Air Traffic Management (ATM) system on the ground that supports the exchange of DAP information [9].

CARD (Conflict and Risk Display) is a handy tool when it comes to visualization of a detected conflict. An ATCO can highlight the detected conflict or choose to remove the highlight as they please, depending on the subjective severity of the conflict. CARD will also warn the ATCO by changing the colour of the conflict to indicate an increased or decreased severity of the situation.

Flight leg and flight leg embellishment aid ATCOs in predicting future traffic situations and potential conflicts by allowing them to visualize the aircraft route. While flight leg only shows the aircraft route, flight leg embellishment also shows potential conflicts with other aircraft and their routes by colour coding. Green indicates no conflict, yellow shows a potential conflict of less than 12 NM of horizontal separation and no vertical separation, while red indicates a conflict where aircraft will be at less than 5 NM horizontally without vertical separation.

Some other tools that can be mentioned are Heading vector (assignment of headings and/or direct routing), Range rings (concentric circles around a specified point), Scale marker (graduation line), Geographical reference (geographical reference for a selected point on the radar image), Level band highlight (filtering the flight levels), SAP (Segregated Area Probe that lists warnings/conflicts) and Vertical Aid Window (predicted vertical profiles of aircraft flying through a sector). There are also some generic tools for monitoring, crossing traffic, filtering traffic, etc. Such tools are usually colour-coded as it catches the eye of the controller easiest.

### B.6.2 Warning systems

In order to warn air traffic controllers that might have lost situational awareness, safety nets are used. They help in the prevention of an impending or a real hazardous situation from evolving into an incident or an accident. They can be either ground-based or airborne, and ground-based ones are the ones used by ATCOs. Ground-based safety nets are able to provide warning times that are up to two minutes. Once they receive an alert, ATCOs should react in a timely manner and evaluate the situation in order to take suitable action.

The following safety nets are commonly used in ATM automation systems:

- Short Term Conflict Alert (STCA) - helps the ATCO in prevention of collision between aircraft by generating an alert on time, that warns the ATCO about a potential or actual infringement of the separation minima.
- Area Proximity Warning (APW) - the ATCO is warned about unauthorised airspace penetration by generating an alert on time to divert ATCO's attention to the potential or actual infringement of required spacing.
- Minimum Safe Altitude Warning (MSAW) - the ATCO is warned about an increased risk of Controlled Flight Into Terrain (CFIT) by generating an alert on time about the aircraft proximity to terrain or other obstacles.
- Approach Path Monitor (APM) - the ATCO is warned about an increased risk of CFIT by generating an alert on time about the aircraft proximity to terrain or other obstacles during the final approach [10].

### B.6.3 Voice communication

Communication between ATCOs and pilots is an important process crucial for the safety and efficiency air traffic. Voice communications between a pilot and the ATCO are usually accomplished using radiotelephony, broadcasting, and receiving on UHF (Ultra high frequency), VHF (Very high frequency), and HF (High frequency). VHF is vital for arrivals and departures, while HF usually serves for long-range communication and weather forecasts. UHF stations are mostly used in communications with military aircraft flying as operational air traffic (OAT). There is also use of a Satellite Communication (SATCOM) datalink but it is used only for a small proportion of en-route ATM communications which contrasts the extensive use of VHF and HF.

CPDLC (Controller Pilot Data Link Communications) is a two-way data-link system made as a resort to voice communications. Controllers can use it to transmit non-urgent messages to an aircraft and those messages are then displayed on a flight deck visual display. CPDLC is a great alternative to traditional air-ground data communication as it enables the exchange of communication messages (clearance, information, request, etc.) which correspond to standard radiotelephony. Controllers can issue ATC assignments, transfer aircraft to different radio frequencies, and request various information. Pilots can easily respond to messages, request and/or receive clearances and information, and report information. There is also a „free text“ capability used to exchange information that does not conform to predefined formats [11]. However, such communication via free text is discouraged as it can lead to misinterpretation. There is also a lack of possibilities as it is not yet possible to issue restrictions along with the clearances (e.g., rate of climb or rate of descent) and insufficient implementation of CPDLC in aircraft.

# Appendix C Artificial Intelligence

Artificial intelligence (AI) is defined as the ability of a digital computer or a robot to perform tasks commonly associated with intelligent beings [16]. Artificially intelligent machines are programmed to solve complex problems using if-then rules, as opposed to the conventional procedural code [17]. The result of such programming is a machine whose actions resemble the thought process of a human. Artificial intelligence went through three major stages since it was first popularized in the 1950s [18], [58].

The Expert systems in the first wave were designed to simulate human reasoning for specific problems in narrow domains (e.g., medical diagnoses). This method relies on coded logical rules and is unable to autonomously learn from data. First wave systems are therefore brittle at handling uncertainty, with no ability to abstract new concepts (i.e., develop more general rules) from data. Their advantage, on the other hand, is interpretability, the possibility to trace the exact chain of reasoning that led to a certain conclusion [58].

The second wave of AI focused on Machine learning (ML) methods. Machine learning is the science of getting computers to learn and act in the same way humans do, with improving their learning over time autonomously by being fed volumes of big data in the form of observations and real-world interaction. Their training depends exclusively on the training data since there are no explicit hard-coded rules. The basic goal of machine learning is to generalize beyond the examples provided in the training set. This is because, regardless of how much data is used in training, it is very unlikely that those exact examples will ever be seen again at test time. In other words, the goal is for the machine to successfully process data it has never „seen“ before. Machines that can learn are useful to researchers because they can quickly highlight or find patterns in the massive amount of data that would have otherwise been missed by human beings, all due to their processing power. It is a tool that can be used to improve humans' problem-solving abilities and make informed assumptions on a wide range of problems [58], [59].

The second wave extension is based on the statistical-based deep learning which requires many training exemplars. Deep learning has an improved capability of generalization due to its approach to discovering more layers of hidden variables. The strategy used is raw brute force approach, where there is a lot of data to build a complex solution with the optimization process that tunes all the parameters in all the layers to have a solution applicable to a great number of situations [58], [59].

The downside of the machine learning defined in the second wave and the second wave extension is a lack of transparency/explainability. The problem is that the system works as a Black box, meaning its operation is not visible to humans. The results, even though they may be correct, are hard to explain and non-intuitive. The research on AI continues in the way of trying to achieve an understandable and verifiable process [58].

In the third wave, it is expected that the artificially intelligent machines will be able to generalize and explain their working process. Explainable, transparent artificial intelligence is vital for future users to trust, understand and supervise their artificially intelligent machines. The goal of the Explainable AI (XAI) is to develop machine learning techniques that can generate more transparent models, while not compromising the high level of learning performance [58], [60].

# Appendix D Polls

## List of tables



## List of charts

The AISA project organised its first workshop on the 16th of September 2020. During the online event, the consortium presented the draft of this Concept of Operations for the proposed ATM Artificial Intelligence Situational Awareness System. The workshop was repeated in three time slots (10:00, 13:00 and 15:00 Central European Time) to ensure better interactivity. The workshop session had 65 participants and all the sessions had good discussion sections, questions and comments on several issues. The workshop was provided by WebEx and several SESARJU and EUROCONTROL experts also participated. All three sessions started with the presentation of the AISA Concept of Operations presented by Tomislav Radišić. The presentation took about 45 minutes and was followed by 45-minute sessions consisting of questions from the audience and a consequent discussion.

The questions asked during the sessions regarding the polls were as follows:

1. What is your professional background?
2. What is the time period you think that AI can be introduced in ATM in an extensive manner?
3. What are the biggest challenges with introducing AI into ATC operations? (Multiple answers possible).
4. Do you think it is possible for human and AI to share the situational awareness?
5. What kind of activities do you think AI will do in ATM by the time the SESAR Master Plan is fully implemented? (Multiple answers possible).

## D.1 Tables

| | What is your professional background? |
|---|---|
| Academia | 46% |
| ANSP | 9% |
| Airspace user | 3% |
| Airport | 0% |
| Equipment/software manufacturer | 1% |
| Regulatory body | 5% |
| Military | 0% |
| Consulting | 5% |
| Other | 8% |
| Not answered | 23% |

**Table 1 Question 1**

| | What is the time period you think that AI can be introduced in ATM in an extensive manner? |
|---|---|
| Before 2030 | 18% |
| Between 2030 and 2050 | 51% |
| After 2050 | 2% |
| Not answered | 29% |

Table 2 Question 2

| | What are the biggest challenges with introducing AI into ATC operations? (Multiple answers possible). |
|---|---|
| Safety | 43% |
| Effectiveness | 6% |
| ATCO out-of-the-loop effect | 31% |
| ATCO de-skilling | 25% |
| Shared liability | 18% |
| Regulatory framework | 26% |
| Other | 2% |
| Not answered | 31% |

Table 3 Question 3

| | Do you think it is possible for human and AI to share the situational awareness? |
|---|---|
| Yes | 45% |
| No | 2% |
| Not at this stage of AI development | 15% |
| Don't know | 6% |
| Not answered | 32% |

Table 4 Question 4

| | What kind of activities do you think AI will do in ATM by the time the SESAR Master Plan is fully implemented? (Multiple answers possible). |
|---|---|
| Monitoring tasks | 58% |
| Information analysis tasks | 49% |
| Decision-making tasks | 18% |
| Action implementation tasks | 15% |
| Not answered | 35% |

**Table 5 Question 5**

## D.4 Charts

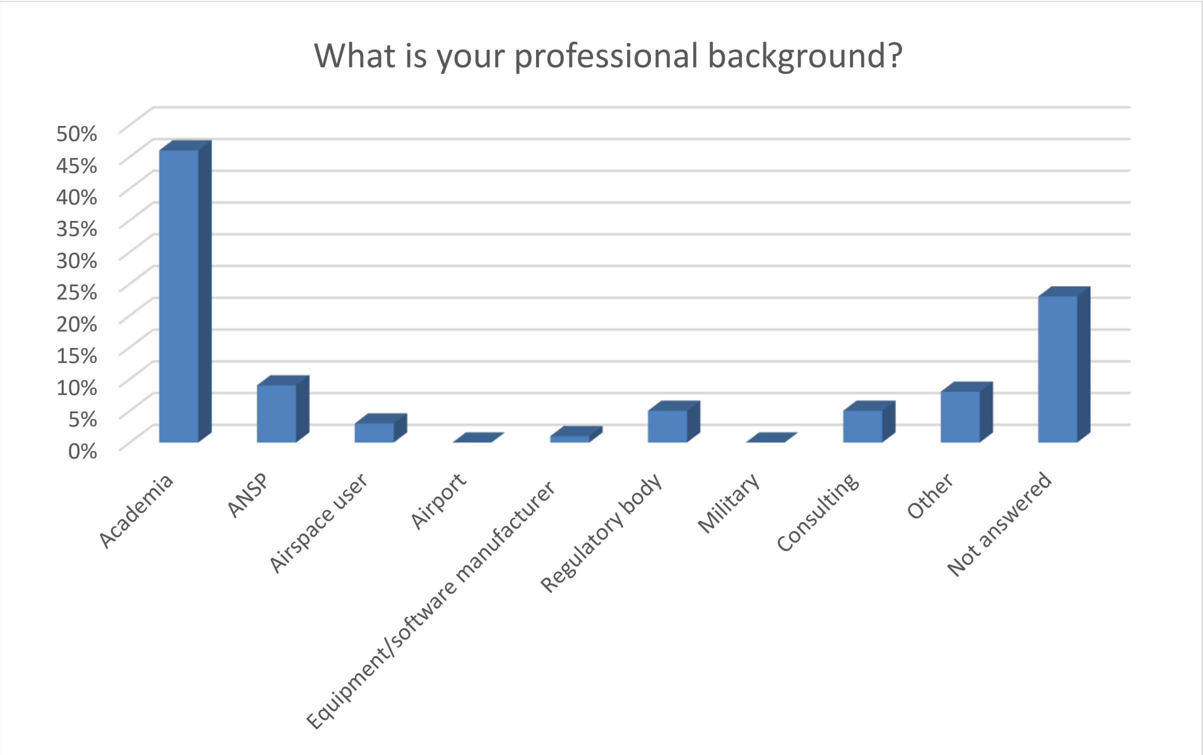


**Chart 1 Question 1**

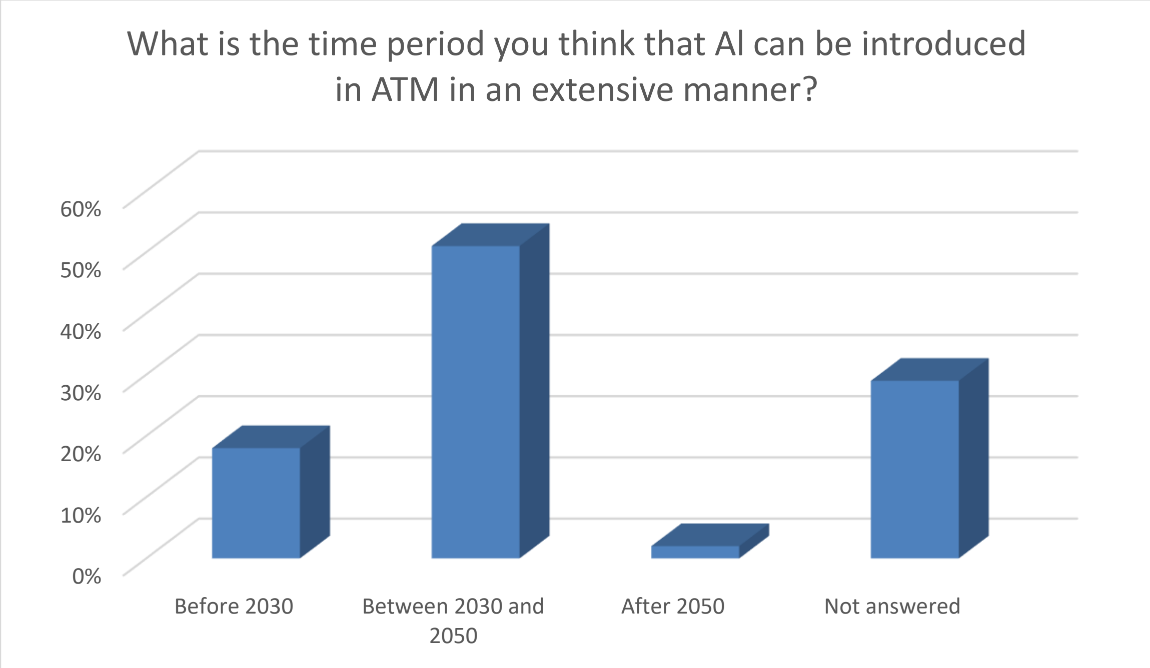


**Chart 2 Question 2**

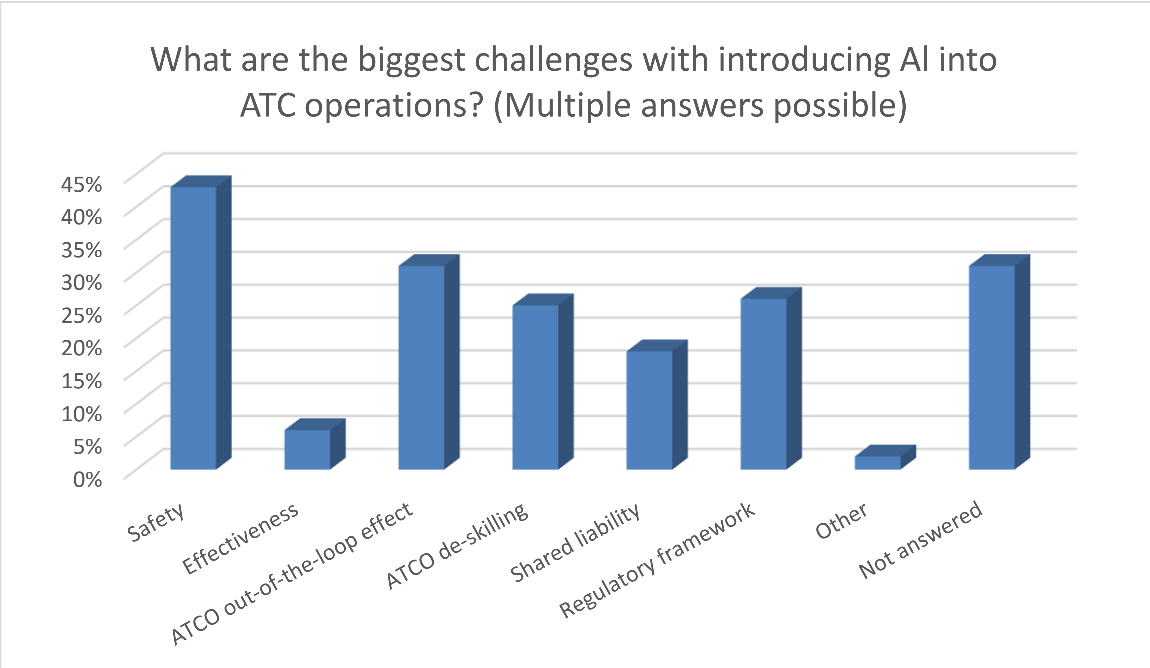


**Chart 3 Question 3**

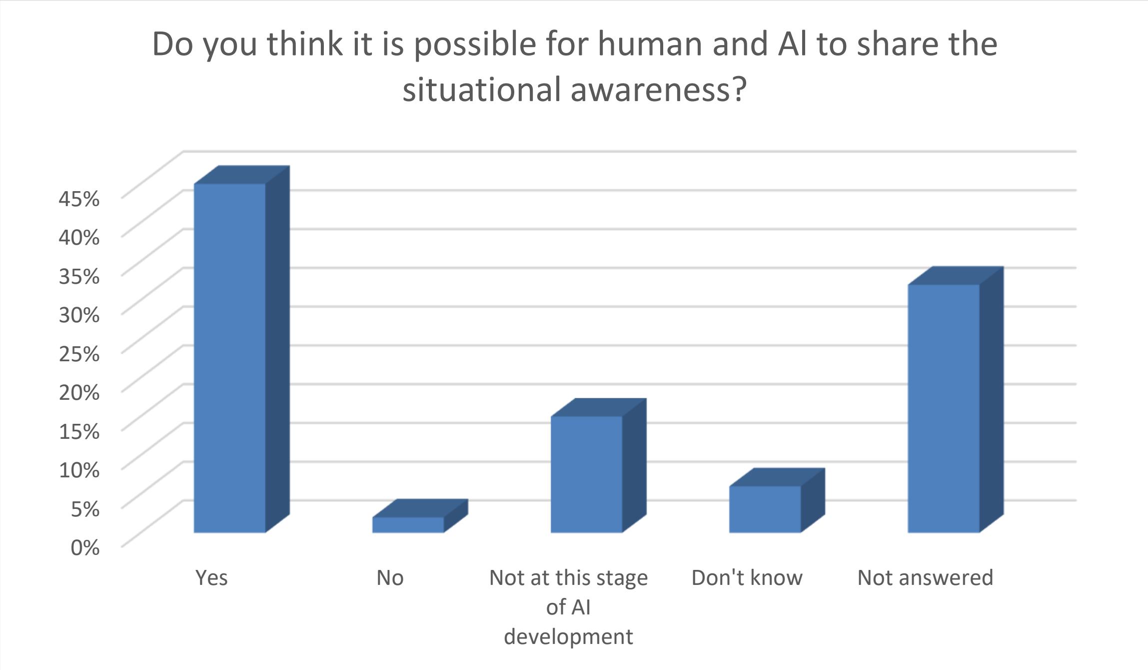


**Chart 4 Question 4**

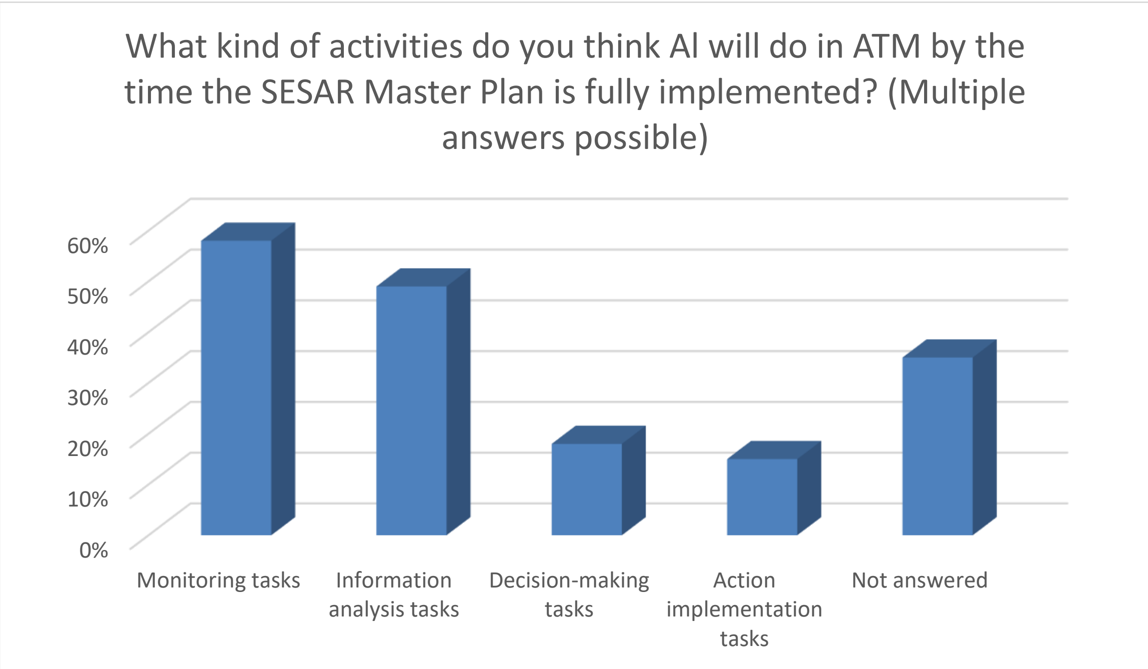


**Chart 5 Question 5**