Requirements for automation of monitoring tasks via AI SA

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AISA

AI SITUATIONAL AWARENESS FOUNDATION FOR ADVANCING AUTOMATION

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Abstract

As this document builds on the Concept of Operations of the AISA project, it starts by referring to the main findings in the other deliverable and then it continues with the assumptions and limitations of the requirements generation process. The methodologies section shows how the requirements were gathered and validated.

The requirements are introduced at two levels: first they are presented at a conceptual level, describing that at the present knowledge what kind of requirements should be fulfilled during the future introduction of artificial intelligence into air traffic control. Also, the first monitoring type of air traffic control tasks are selected, where the introduction of AI, acting as a team member for air traffic controllers, should start. The document concludes with a few requirements that are set for the experiments within the project, on what bases the modelling activities should be performed.

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1 Introduction

1.1 Purpose

This deliverable is based on work package 2 (WP2) Task 2.2 **Analysis of requirements** for automation of monitoring tasks via AI situational awareness (SA) of the AISA project.

This analysis will show 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 the user interface, and the possible effect on human operators. Also, in this task, requirements for knowledge engineering of selected tasks will be defined.

1.2 Intended audience

There are two main groups of the intended audience:

- Experts from the related fields,
- The AISA consortium.

The analysis of requirements for automation of monitoring tasks via AI SA deliverable (AISA D.2.2) is important for the consortium as:

- In the frame of the work of WP2, it will help in the preparation of the Concept of Operations for AI Situational Awareness System (AISA D2.1)
- The document will provide direct input to the other technical work packages (WP3, WP4, WP5) and the related deliverables, by showing the selected ATCO task portfolio likely to be suitable to be accomplished by AI and also by setting the boundary requirements of the future system.

The document is also useful for external stakeholders, especially the following ones:

- ATM system developers who would like to understand how AI can be integrated into ATM,
- ATM experts conducting related research,
- General automation and AI experts who would like to see the possible use of AI in a new domain.

1.3 Associated documentation

The document is linked to several SESAR and ATM documents, here only the most relevant ones are listed:

- AISA D2.1: Concept of Operations for AI Situational Awareness System [1]
- AUTOPACE project D2.1: Future Automation Scenarios [2]
- AUTOPACE project D5.1: Final Projects Results Report [3]

- Episode 3 project: Today's Operations Task Analysis - Human Factor Assessment [4]

1.4 Terminology

The requirements set up in this document are useful on one hand for the AISA model developed in the project and on the other hand for the future building of real TRL 9 AI systems. Therefore, it is important to distinguish between the AI Situational Awareness and AI Situational Awareness Model.

AI Situational Awareness System (AI SAS) will be the operating system in the future implemented by ATM system providers. It means the future ATC system together with an AISA AI engine. In some cases, the system is referred to as "AI-based support system", and the "system".

AI Situational Awareness Model (AI SAM) is the model developed within AISA and which represents such core functions of the future system (AI SAS) which is relevant for the project.

Artificial Intelligence is a science and engineering of making, human-like intelligent machines/systems.

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.

ATC system is the set of systems the ATCO is using including the ones which are working in the background and directly linked to the primary ones visible for the ATCO.

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

Concept level requirements are those requirements which are to be used by subsequent research and development activities in the future in the AISA timeframe (2035 and beyond).

Monitoring as an expression is used in two different manners in this document. First of all, as the work plan indicates, AISA plans to start primarily with those "monitoring tasks" which currently (2020) require only monitoring type of contribution by the ATCO either due to the relatively significant level of automation or because the task itself is simple and requires no more interaction than monitoring. On the other hand, in the terms of the classification of future tasks among human and machine, "monitoring" means if in the future (medium or long-term scenario) a task is so highly automatised (with AI involvement), ATCOs will only need to perform monitoring activities.

Project level requirements are those requirements which are to be used during the AISA project by the other technical work packages.

Situational Awareness is the perception of environmental elements and events concerning time or space, the comprehension of their meaning, and the projection of their future status.

Shared Situational Awareness means that two or more persons (or in the case of AISA: machine as well) have a commonly understood mental image of what is happening and/or what is going to happen in the near future.

Traditional automation is a kind of automation that unlike artificial intelligence, gives a definite answer to certain outputs and is unable to learn or improve itself.

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

2 AISA and its environment

Two different kinds of related information are introduced in this chapter in a relatively short manner:

- general information on the "environment" of AISA, e.g. the status of development of the targeted or neighbouring disciplines in terms of the main AISA research question,
- main project related information that provides an essential background for the understanding of the project related requirements.

2.1 Related research and development status

The main research question of AISA is the following: *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?*

Therefore, the three relevant disciplines and the related issues to be investigated are:

- Air traffic management: the status and the foreseen development of automation in ATM,
- Information technology: the role of artificial intelligence within the general automation tendencies,
- Human factors research: situational awareness with machines involved.

We have two related statements before starting the analysis:

- All the investigated fields above are quite new and as it is usual in research: there are a lot of debates and competing ideas, classification on them. The AISA project cannot judge all the findings, classifications or debates individually and we list one likely option on all the three areas here only to provide a piece of short background information to the reader of the document, the concerning theoretical debates have no direct relation to the intended project results to be delivered.
- The introduction of the related scientific fields and research issues are intentionally kept short as this is not the focused part of the document. Further references are given to give directions to those readers who would like to research further to certain directions. Also, the AISA ConOps document provides a more extensive description of these issues.

2.1.1 Automation and AI

It is necessary to define the relation of automation and artificial intelligence before going further in the analysis. Automation as mentioned in the terminology section is the creation of a technology that will execute a certain task, or a certain set of tasks automatically. Although several categorizations exist, to keep the analytical background relatively simple, in this document we make two sub-categorizations of automation:

- Traditional automation,
- Artificial intelligence.

Under *traditional automation,* we mean the "everyday" routine type of automation, where the program uses a pre-coded algorithm and it gives a definite answer for a certain set of inputs. If automation is done right, the output can be predicted from the input and the uncertainty is zero. On the other hand, the traditional automation system is unable to learn and to improve itself [5].

Artificial intelligence (AI) is very different from traditional automation as the intention is to build a system which, like human beings, can learn and to adapt to circumstances. The "cost" of this intelligent function is a degree of uncertainty just like with the decisions of human beings [5].

The comparison of the main characteristics of systems using traditional automation, human beings and systems using artificial intelligence is summarised in the table below:

	Uncertainty	Creativity
Traditional automation	NO	NO
Human being	YES	YES
Artificial intelligence	YES, but decreasing	YES, and increasing

Table 1 Comparison of the main characteristics of systems using traditional automation, human beings and systems using artificial intelligence

The table above shows that AI is closer to a human being than to traditional automation. Some degree of uncertainty is always present, but the system can adapt, learn and to come up with own suggestions. We use "creativity"[1] in terms of learning from the past and come up with something new based on past information/experience. It's important to note that AI can learn very quickly from sets of big data information, so the level of uncertainty regarding its decisions can be radically reduced, but on the other hand, the ability to invent something new can also be increased.

In AISA we consider Machine Learning and Reasoning Engine as AI-related concepts. Consequently, when AI is mentioned, these related concepts are always meant to be behind the future envisaged AISA solution, namely AI Situational Awareness System (AI SAS) and also the project related outcomes: the AI Situational Awareness Model (AI SAM).

Besides, it should be mentioned that AI and AI SAS, in particular, will enable better performance of automation in general, initially by monitoring the status of legacy systems and provide a warning in case of non-performance and later by exploring new and better ways of using them.

2.1.2 Automation and ATM

As in most industries, there are significant driving forces for automation in air traffic management. The two main driving forces are increasing efficiency and being able to cope with new emerging external technologies. Besides traditional automation, there is increasing motivation to introduce AI to ATM as

[1] Here we are using a kind of "narrow" definition of creativity as there is a debate about if AI can be creative or not, or what extent can it be creative and by when.

well, but as with any other safety-critical industries, this should be approached with special care. The recent "Fly AI Report" [6] tries to give a guideline framework for AI implementation in aviation.[2] The AISA project acknowledges the findings of this report and any other similar actions and related main research programmes, such as in the field of avionics[3]. In the current document, we plan to avoid the duplicate what is already written in this report, although certain overlap with the requirements set (despite the less general focus) is inevitable.

The document also finds that there are some projects which already use AI in some kind of form (mostly machine learning technologies), but AISA's intentions are different than those current applications. The AISA project plans to provide a solution which goes much further than the current applications in terms of the technology used and tries to offer a generic solution which is going to be part of the core of the ATC systems and will especially be able to support en-route air traffic controllers (ATCOs).

AI as a potential enabler to meet the future air capacity demand – The demand for airspace and airport capacity is expected to rise continuously towards 2030. As the traditional means of relieving congestion and improving efficiency by splitting the airspace into sectors and by staffing ATCOs will not be able to solve such demand, we should prepare to use AI and ML to our advantage.

AI today in development and trainings - When speaking of recent development and progresses in AI and ML in the ATM, EUROCONTROL's integrated Flow Management Position (iFMP) at Maastricht Upper Area Control Centre analyses the routes that ATCOs give to aircraft, to find out if paths can be identified to make them more standardized. Bringing adaptive teaching in ATCO training via e-learning and simulation is on raise as well. For a specific training exercise such as "turning final from downwind", AI could present the most effective landing sequence to the student ATCOs by calculating winds, wake turbulence separation, speed, etc. much faster than human. Furthermore, AI could show alternative solutions with good reasoning and coaching capabilities to enhance the individual learning experiences, therefore, helping to learn faster.

AI in future potential application – According to "the FLY AI REPORT 2020", the aim of AI applications and expected benefits in ATM are numerous. For instance, in the area of traffic predictions and forecasting modelling where many ANSPs could benefit, AI could improve prediction of aircraft trajectories such as climb trajectory, final approach sequences or the optimal configuration of sectors.

A trustworthy AI - While there is a clear need for sustaining the airspace capacity by AI/ML in the future to compensate the limited human resource and cognitive capabilities, the society still faces divided opinions about the AI as potential use in ATM. Such a notion may hinder the progress of AI development, live-trials and eventual implementation. Some consider AI as the ultimate solution to all of the current and future problems, whereas the others form scepticism or fear over the AI and its reliability and trustworthiness in a safety-critical industry such as ATM. It is, therefore, crucial to

[2] The Fly Ai Report - Demystifying and Accelerating AI in Aviation/ATM (References)

[3] The Clean Sky DISCO project for example researches the use of disruptive technologies that would enable single pilot operations.

develop the framework approach among various aviation stakeholders and policymakers towards developing safe and step-by-step introduction of AI technology.

2.1.3 Team situational awareness with machine involved

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 [7].

Team or shared situational awareness means two or more persons have a commonly understood mental image of what is happening and/or what is going to happen. In terms of the AISA concept, machine/system should be treated as a person because, in this scenario, the system is part of the team.

One of the recently discovered problems with automation is the Out-of-the-loop (OOTL) effect of the system operators. The same problem might affect ATCOs. There are already several research actions dealing with that problem in the field[4]. The main question that AISA is addressing is how to overcome this by enabling both the ATCO to be aware of *what the system knows and also to enable the system to be aware what it knows/does not know and what the ATCO knows?*

2.2 AISA project information

2.2.1 The AISA Concept of Operations

The AISA Concept of Operations (ConOps, AISA D2.1 [1]) document describes how the future AISA concept will work, what the future will be, as well as the future scenarios and how the ATCOs and the future ATM system will cooperate. The current document is building on the ConOps and it is a description of the future system, the role AI SAS will have and what it is supposed to do to achieve the objectives defined in the ConOps.

The current document is not meant to describe the future AISA concept. It is advised that any reader of this document reads the AISA ConOps first. Therefore, to avoid duplications, references are made to the ConOps wherever possible, but conceptual descriptions are usually missing from the current document.

2.2.2 The AISA architecture

Although the AISA architecture is described in the ConOps, it is also included here with a short description for easier reference. In Section 6, a more detailed look at the proof-of-concept KG-based system, as planned for development in the project, will be presented. The AISA approach combines

[4] The AUTOPACE SESAR ER project for example focused on the OOTL effects as well.

reasoning engine employing predicate logic (first-order logic) based on ATC knowledge graph system with machine learning (ML) approach for prediction and estimation (Figure 1). ML is used at a lower level to predict individual probabilistic events (e.g. estimated time over waypoint) whereas reasoning engine is used at a higher level to draw conclusions from the system state. By combining reasoning engine with ML, AISA investigates whether it is possible for AI to be 'aware' of the situation like 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.

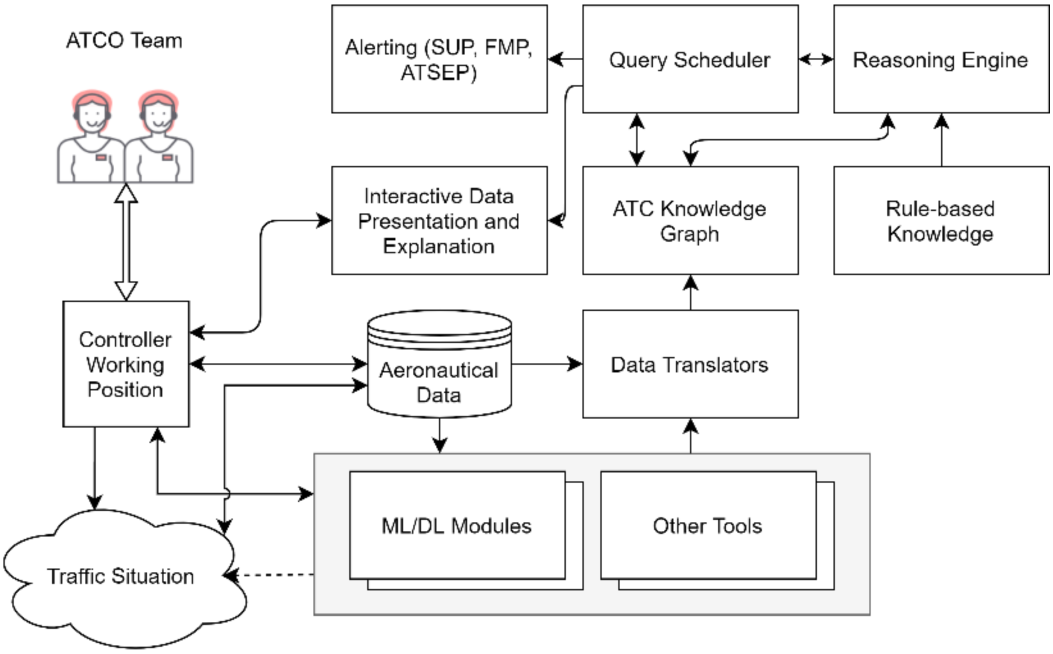

Figure 1 Conceptual architecture

3 Assumptions and limitations

This document has several assumptions to provide a framework for why and how the requirements are set. These are decisions made by the consortium with a short explanation in certain cases. In most cases, a more detailed explanation is provided either in this document or in the ConOps.

3.1 AISA assumptions for the requirements development

Assumption 1: Artificial intelligence is part of automation, but it is different from traditional automation.

Assumption 2: Artificial intelligence is a new technology, where a level of uncertainty is always present, therefore cautious planning and probably a longer time scale is required when it is introduced to a safety-critical industry like ATM.

Assumption 3: The AISA consortium considers that those tasks where the air traffic controllers currently perform only monitoring type of tasks are simpler and easier compared to those where a higher level of interaction is to be made. The assumption is that it is better to choose relatively simpler activities for the introduction and testing of new complex methods, technologies, solutions.

Assumption 4: The AISA Situational Aware System (AI SAS), also called the “system” in certain parts of the document is considered the legacy ATC system (the set of systems used at a certain ANSP by ATCOs) together with the new conceptual AISA AI engine.

3.2 AISA limitations for the requirements framing

Limitation 1: AISA is a TRL-1 exploratory project which shows initial conceptual directions for a possible future system only, therefore the usual requirement setting methods are only partially relevant.

Limitation 2: In the deliverable, the related requirements, requirements examples and guidance for the future requirements will be presented at two levels: at future conceptual and at a present project level. Not all the requirements will be presented at both levels as some are relevant only at a certain level, or in some cases, the development at another level is not yet possible. This distinction and the reasoning for limitation is explained in the applicable sections.

Limitation 3: Due to the quick changes both in automation and ATM technologies, defining exact requirements for the future is not advisable. Therefore, in this document, concept level requirements are either qualitative or are present as examples.

Limitation 4: Project-level requirements are focusing on the needs of the laboratory environment where the modelling takes place. They are, therefore, not meant to provide an entire set of requirements needed for the development of an AISA like system.

Limitation 5: Subsequent technical work in work packages has a narrower focus than this document and a degree of uncertainty at the time of closing of the requirements. Therefore, the current project level requirements are meant to serve a suggested framework, from which the experiments can choose examples.

Limitation 6: When introducing AI to ATM there are European network related issues to be considered. In that case, the overall European ATM system should be taken into account. Due to the theoretical nature of the project, this document focuses on the introduction of AI at the level of a certain ANSP only.

Limitation 7: The monitoring type of ATC tasks chosen are relatively less safety-critical directly (compared to other ATC tasks), but indirectly they are also representing a significant safety-critical element, as non-performance or low-performance of monitoring type of activities can lead to missing or wrong decisions which are safety-critical issues. Therefore, even though the chosen monitoring tasks are considered less safety-critical than others, their implementation and the control of the implementation period has to be treated with special care.

4 Methodology for identifying the requirements

The requirements identified in this document fall into the following two main categories:

- Concept level requirements for the AI SAS for a longer time horizon (e.g. 2035 and beyond),
- Project level requirements for the AI SAM for a short-term period (during the project).

The reasoning is that the document has two main purposes: to support researches in the field of ATM and automation in general and to provide input to the subsequent technical work packages (WP) within the AISA project. Therefore, the related methodology is also split into two sub-chapters as shown below.

In terms of the classification of the importance of requirements in this document, two kinds of categories are established:

- Requirements starting with *"shall"* are a mandatory requirement which the proposed concept or model should meet.
- Requirements starting with *"should"* are a recommendation to what direction the concept or the model should progress according to the current knowledge of the AISA consortium.

4.1 Methodology for setting up the requirements for the AISA concept

This section presents the high-level, generic requirements and some examples as guidelines for more specific, functional requirements at the AISA concept level. The aim is to support researchers and system developers who are working in the same research field and/or aiming to develop AISA-like systems. At the AI SAS level, requirements and the associated methodology to develop the requirements are divided into two main groups:

- Generic/non-functional requirements,
- Functional requirements.

4.1.1 Generic requirements generation

In this document, the word "generic" doesn't apply to the exact requirements of a system, but rather presenting an approach to what kind of requirements will need to be specified once the system development reaches that status.

Non-functional requirements are also called quality attributes. They show what a system should look like and what kind of attributes it should have. The methodology to generate them is relatively simple. The authors of this document reviewed the associated similar digitisation requirements, reviewed them and adapted them to the needs of AISA. After a consortium wide review, they were fine-tuned. It is important to mention that the AISA consortium includes experts from all three associated disciplines:

- Air traffic management/control both at a theoretical and practical level,
- AI/automation/digitalisation and associated technologies and models,
- Human factor/psychological concepts, models, tools.

In this manner, an internal early validation cycle is ensured.

4.1.2 Functional requirements generation

Functional requirements present what the system is supposed to do. In the AISA case, they mainly show what kind of ATC tasks and sub-tasks the system should overtake or, at least, support. The first step, therefore, is the identification of those ATC tasks where AI can have a role in the given timeframe.

To find the right list of air traffic management related tasks, the following steps were taken:

- The main ATC tasks according to the Episode 3 project are listed
- The AUTOPACE categorization for different modes of automation is applied
- Those tasks where the future system might start to be involved are selected, e.g. the monitoring tasks
- With the help of air traffic controllers, those tasks where it is the most likely that an early extensive AI usage is introduced are selected.

After having selected the tasks, some sub-tasks are singled out as examples and requirements are generated in the normal functional requirements format.

4.2 Methodology to establish the requirements for the project activities

For the AISA project activities, namely for WP3, WP4 and to some extent WP5, the requirements are set differently. The AISA architecture shows how the AI SAM will be built. However, according to our current knowledge, it is very difficult to judge whether such an architecture would be useful in the 2035 (and beyond) timeframe as ATC tasks are evolving. More importantly, there is a revolutionary development in the field of digitisation and especially in the field of AI. Therefore, the detailed requirements might become obsolete quite soon. As a consequence, in this document, we define detailed requirements only at the project level, namely in the field of the machine learning module (WP3) and the reasoning engine (WP4). These WPs will choose from the scenarios provided in their work and will use the associated requirements when doing the exercises in the model.

The requirements are therefore set in a joint work of automation experts, ATM researchers and ATM end-user experts.

4.3 Sources and feedback channels

The consortium was using the following sources during its work:

- Available documentation and the knowledge of the consortium on current issues and gaps. The process included the analysis of the relevant ATM and automation related regulations, publications, SESAR documents, deliverables from other projects in the field (e.g. AUTOPACE, BEST, EPISODE3) which may provide a baseline for further work and/or additional set of issues, gaps, necessities to be solved.

- Feedback of internal experts in the different relevant disciplines.
- During the ConOps preparation process, the feedback of external experts and stakeholders was extensively used (AISA ConOps workshop, Advisory Board and other experts' opinion) and these feedbacks validated and fine-tuned the concept on which the requirements are set.

The selection of monitoring tasks that are the best suited according to the current knowledge to start to use a future AISA like system was done in a validation process with air traffic controllers. During a dialogue between Skyguide, SLOT and FTTS, the following steps were taken:

- First, the ATC task list as proposed by FTTS (also introduced in D2.1, the AISA CONOPS) was validated and updated by Skyguide
- Then, each task was observed according to the following criteria: to what extent it is safety critical, to what extent human-machine cooperation is possible during the execution of that task and to what extent AI can be mature in a relatively shorter timeframe to effectively contribute to a certain task. The less safety critical a task was judged the more grade it received for AISA usage, and similarly the more a certain task was considered to fit for human-machine cooperation and for early AI adaption, the higher grade it received.
- The concluded list shows the AISA suggested monitoring tasks.

5 Concept level requirements

5.1 General requirements

5.1.1 General provisions

The generic/non-functional requirements in this document represent a high-level explanation of what the future AI SAS should look like. **Therefore, this section directly maps to the Section 4 in the project ConOps.** When framing these high-level requirements, we fully acknowledge previous work in this direction as already mentioned in the Automation and ATM section. Besides the mentioned examples, we follow the relevant guidelines from the European Commission as well.

The High-Level Group on Artificial Intelligence (AI HLEG) has created a list of seven solid guidelines to achieve a trustworthy AI [8]. The AISA consortium fully acknowledges these guidelines when developing the requirements and planning the rest of the project work:

1. Human agency and oversight
   - Including fundamental rights, human agency and human oversight.
2. Technical robustness and safety
   - Including resilience to attack and security, fall back plan and general safety, accuracy, reliability and reproducibility
3. Privacy and data governance
   - Including respect for privacy, quality and integrity of data, and access to data.
4. Transparency
   - Including traceability, explainability and communication.
5. Diversity, non-discrimination and fairness
   - Including the avoidance of unfair bias, accessibility and universal design, and stakeholders' participation
6. Societal and environmental wellbeing
   - Including sustainability and environmental friendliness, social impact, society and democracy.
7. Accountability
   - Including auditability, minimisation and reporting of negative impact, trade-offs and redress.

In this document, the level of detail goes a bit further, but for obvious reasons, only a qualitative description of the required future performance is possible at this stage. The section classifies the non-functional requirements in the following three categories:

- Impact related requirements (like safety, efficiency, etc.),
- Human factor related ones (user-oriented ones),
- Operations requirements (operation performance, link to other systems).

Finally, it is important to mention that the consortium does not believe that these are the only requirements when developing AI SAS. The introduction of AI to safety-critical industries is raising a lot of questions and issues and probably will raise many more, so this requirement list should continuously be monitored and regularly updated.

5.1.2 Impact related requirements

The following table shows the impact-related requirements for the AISA system.

Impact area	Requirements
Safety	IMPR_1: The new system with AI-enabled monitoring functions shall be at least as safe as the legacy system without the new AI component.
Security	IMPR_2: The new updated system including the AI component shall be at least as secure as the legacy system without the new AI component.
Efficiency	IMPR_3: The new system shall be significantly more efficient as efficiency is the overall motive for automation.
	IMPR_3.1: The system and its controllers should be able to handle more traffic than the legacy system (increasing capacity).
	IMPR_3.2 With the introduction of the system the occupancy and related stress level of ATCOs should be less than with the legacy system.

Table 2 Impact related requirements

5.1.3 Human factor related requirements

Within the human factor related requirements there are two main sub-categories. One is related to ergonomics/human-machine interface (HMI) the other one to team situational awareness.

HMI can be observed from two different user perspectives:

Impact area	Requirements
User-friendliness for ATCOs	HFR_1 The overall user-friendliness of the system for ATCOs (ATC system with the new AI engine embedded) should be at the level of the legacy system.
	HFR_1.1 The user-friendliness of the system for ATCOs should be better than the legacy system in terms of level and quality of the information provided.
User-friendliness for IT operators	HFR_2 The user-friendliness of the system for IT operators should be at least the level of similar legacy systems.

Table 3 Requirements for HMI

Reasoning:

One of the main reasons for AI usage is to ease the work of humans. For the ATCOs, the AI part should not necessarily be directly visible (e.g. providing an extra system, sub-system, HMI to deal with). It should be incorporated into the general ATC system.

For the IT operators who are doing the system maintenance of the AI sub-system of the ATC system (AI SAS), user-friendliness matters, but at a different scale than for ATCOs. In this respect, user-friendliness should meet the general characteristics of similar systems.

In terms of designing such a system the followings HMI principles should be considered:

- Human-centred design
- Simplicity
- Authority levels
- Consistency in design
- Feedback performance
- Response time
- Alert provision capability
- Error notifications

As the establishment of team situational awareness among ATCOs and the system is the key objective of the project, related requirements should also be set:

Area of impact	Requirements
Situational awareness	TSAR_1 The system shall be able to take part in shared situational awareness.
	TSAR_2 The system should have shared situational awareness with the rest of the team at a level necessary to execute certain tasks with the required confidence level.
	TSAR_2.1 The system should be aware of the situation and its own state.
	TSAR_3 The system shall be able to automate monitoring tasks in a transparent manner.
	TSAR_4 TSA should represent the complete situation with all interactions among aircraft, humans and systems, including accurate representation of the system and human states.
	TSAR_5 The system should have the ability to project future states from current ones.

Table 4 Situational awareness related requirements

5.1.4 Operation related requirements

Operation related requirements refer to the performance of the system in a technical manner. The sub-requirements are mentioned as possible and representative examples, but others might also be relevant:

Area of impact	Requirements
Transparency	OPR1: The system shall be transparent.
	OPR1.1: The system should be able to deconstruct and verify the reasoning chain which led to AI making specific conclusions.

Generalization	OPR2: The system shall be able to generalize.
	OPR2.1: The system should be able to answer to non-routine situations.
Interoperability	OPR3: The system shall be interoperable.
	OPR3.1: The system shall be able to be an integrated part of the ATC system and the overall ATM environment.
	OPR 3.2: The system should be able to assess ATC data in a format compatible with standardised ontologies.
Reliability	OPR4: The system shall be reliable.
	OPR 4.1: The system should maintain the desired functions with the pre-set confidentiality rate.
	OPR 4.2: The system should be available at the pre-set availability rate.
	OPR 4.3: The operations reliability of the system should reach the related performance of the legacy ATC systems it is embedded into.
Speed	OPR 5: The system should be quick in reaction.
	OPR 5.1: The system should do the required job within the expected timeframe.
Flexibility	OPR 6: The system should be flexible.
	OPR 6.1: The system should accommodate adaptations and updates in a facile manner.

Table 5 Operational requirements

5.2 Towards functional requirements

5.2.1 Relevant ATC tasks

5.2.1.1 Incorporating results of earlier related research

The time horizon for the AI SAS implementation is medium-term, approximately 2035-2040. It is relatively short in ATM development perspective. Considering that Artificial Intelligence is a relatively new domain, all related developments should be attempted with special care, focusing on safety issues.

In terms of the methodology to be used in AISA for the identification of possible future ATCO and system tasks, we build on the previous research of the AUTOPACE project. AUTOPACE focused on a longer time horizon than AISA (2050) and on general automation, not specifically AI. Furthermore, AUTOPACE focused on the allocation of tasks among the system and the human whereas AISA is trying to build a shared/team situational awareness where the AI system at the beginning would only have monitoring/support role.

The table below shows the main differences between AUTOPACE and AISA:

	AUTOPACE	AISA
Time horizon	2050	2035-2040
Type of automation	General	Artificial Intelligence
Focus	new ATCO roles	Team SA

Table 6 Differences between AISA and AUTOPACE projects

Despite the differences, the AUTOPACE prioritization is considered as a valid starting point for AISA as it was a thorough review of the main ATCO tasks and was validated by ATM experts and stakeholders. Also, both AUTOPACE and AISA concentrate on en-route operations, where automation is easier to implement.

AUTOPACE has two automation scenarios: High Automation and Medium Automation. Only the second is considered for AISA in detail due to the time horizon differences for the focus of the activities. AUTOPACE sees the situation as follows by 2050 in terms of general roles among ATCO and the system.

"Tasks are shared between ATC system and ATCO.

- In order to reduce workload, ATC system proposes a set of actions that the ATCO needs to approve and implement.
- Some tasks are not fully automated. The ATCO still analyses and decides about the solution to implement with the support of the system, which provides him/her with necessary information." [3]

AUTOPACE considers that the ATC system remains mainly as a support tool in the medium scenario only to advise the ATCO, for example:

- receive information from ATC tools,
- propose tactical actions,
- propose coordination actions,
- support the ATCO in the execution of their tasks.

The different classification of roles is the following:

ATC system:

Apply: the ATC System analyses the situation, decides and implements the most suitable solution on its own according to available information,

Propose: the ATC System proposes to the ATCO a set of actions to implement,

Support: when needed, ATC system supports the ATCO decisions by providing him/her necessary information.

ATCO:

Apply: the ATCO analyses the situation, decides and implements the most suitable solution from those proposed by the ATC system according to the information from the ATC tools,

Approve: once the ATC system has proposed a solution for the conflict; the ATCO must approve it in order to be implemented,

Monitor: when the ATC system is assuming the major tactical actions; the ATCO has to monitor its behaviour to prevent system deviations.

AISA considers a more limited view on the system roles than AUTOPACE from the following reasons:

- As mentioned, the time horizon (2035-2040) is shorter. In terms of ATM system development, this is not a very far away time frame as ATM systems should go through a thorough and time-consuming validation and testing process till deployment. Therefore, the AUTOPACE categorization of the likely system contribution should be downgraded to a realistic scenario for the timeframe.
- AI is suitable to forecast likely outcomes with different levels of probabilities and it is usually used where big data or at least large set of data are considered. Even though fully automated systems are already present, according to our current knowledge it is improbable that AI will be used in "Apply" mode in safety-critical systems such as ATM by 2035-2040.
- Shared situational awareness means that human and machine have the same knowledge on a certain situation/process or at least they have a partial common understanding that enables cooperation. This is different from the AUTOPACE concept which investigated which tasks can be automated and to which level mainly building on system maturity aspects. There are some tasks where full automation is easier than real cooperation. In AISA those tasks should have a higher priority where human and machine can work together better, they can form a "team".

5.2.1.2 AISA related role classification

For the main AISA time frame objective (e.g. SESAR Master Plan implementation around 2035) we consider the following kind of roles of the machine (AI) and human when performing the chosen tasks to implement:

AI SAS	ATCO	Probability
Support	Apply	High
Propose	Approve	Low
Apply	Monitor	Unlikely

Table 7 Roles of human and AI at particular tasks

The table above has two main messages:

1. There is a reverse relation among system and ATCO related tasks in automation. When considering the role of human and machine, the usual relation is that the higher the level of automation, the lower the human interaction. This is not a technical necessity but rather an efficiency-related drive from the economy. The main drive for automation is to increase efficiency, which can be achieved either by decreasing the level of human involvement in general or by increasing the level of tasks done by the machine and human together. In both cases, human involvement per task is decreasing.
2. As AI is a new and therefore relatively risky technology, a gradual implementation process should be maintained, especially as ATM is a safety-critical industry. First, those tasks to accommodate an “embedded” AI will be chosen, where mistakes, failures, malfunctions (if any) have no direct impact on the safety of the operations, e.g. where it is relatively easy to make mitigation by the human and other (non-AI) parts of the system.

As mentioned in the terminology section, “monitoring” has two different meanings in AISA. First, the AISA project focuses mainly on those ATC tasks where the current ATCO role is mainly monitoring. These monitoring tasks are not the same as the monitoring activity when in the future, the level of automation (assumingly with the inclusion of AI) is so high that the ATCO only has to monitor the outputs of the system. The term “MONITOR” in the table above refers to the second category.

As an outlook for the longer term (2050 and beyond) we envisage the following situation:

AI SAS	ATCO	Probability
Support	Apply	High
Propose	Approve	Medium
Apply	Monitor	Low

Table 8 Roles of human and AI at particular tasks in the future

The table describes that in the longer term (e.g. around 2050 and slightly beyond) we foresee that AI-related technologies, like AI SAS or any similar solutions, will be more intensively used. However, as the AISA consortium follows a conservative approach, the current “engineering” prediction is that the use of AI in “Apply” mode in ATC is low. This statement, however, should not be meant as a “visionary” prediction, as it is likely that the technology itself will go through significant development and once that happens, such priority lists should be revisited and updated.

5.2.1.3 Timeframe and implementation speed

Information technology is a rapidly developing industry where the speed of the development is not easy to judge, especially not for decades ahead. This is especially true for “disruptive” new technologies such as AI. On the other hand, the aviation industry and the ATM sector currently face a high-level of uncertainty.

Therefore, the timeframe set by AISA should be considered cautiously. The scenario of implementation is a relatively conservative one. More optimistic experts consider the robust implementation of AI in ATM to happen much sooner. What is important is that we consider certain tasks to be the first ones to test AI with. In other words, the sequence of implementation is important, while the concrete time forecasted is not certain.

5.2.1.4 The initial list of ATC tasks

Defining what an air traffic controller does is not an easy process. It is a very complex job and its definition can range from very high level to very low level. The task list provided by the former Episode3 project is also suitable for AISA. It is a list of several ATCO roles, which is a manageable level and number for further analysis (see table below). Based on the tables in Section 4.5.1.1 of the project ConOps, a set of monitoring tasks was extracted and summarized in the list below. The tasks selected are those which are considered as monitoring tasks by the ATCO. We assume that the ATC tasks, in general, will be the same or will be very close in the middle time horizon as well, with the main difference being that part of the tasks currently done by an ATCO will be done by the system in the future and part of the new system job will be directly or indirectly done by the AI.

Once the set of monitoring tasks was extracted from the description of the role of AISA in the future ConOps (Section 4 of the project ConOps document), the list was also reviewed by the ATM experts of the AISA consortium and it was confirmed/updated.

The initial list of the current “monitoring tasks” which are candidates for future AISA work is the following:

- detection of incoming traffic,
- identifying entry/transit/exit problems, including required climbs/descents,
- monitoring conformance of aircraft to the planned trajectory,
- identifying conflicts,
- monitoring evolution of conflict solution,
- identifying opportunities for improvement of quality of service,
- identifying missing information needed to solve a problem,
- identifying aircraft with possible equipment degradation,
- monitoring adverse weather areas and restricted airspace.
- identifying workload with specific aircraft according to companies and pilots expected behaviour
- monitoring situations at neighbouring sectors (training, assessments, sector load, etc) as well as adjacent units/ANSPs,
- monitoring of the status and performance of ATC sub-systems.

According to the AUTOPACE categorisation, the low-risk tasks selected for AI involvement will all fall into the category of “Support” from the system point of view and “Apply” from the ATCO point of view in the medium term as ATCO will still be in charge for all the decision making and decision execution.

Responsibilities	ATCO	System
Detection of incoming traffic;	Apply	Support
Identifying entry/transit/exit problems, including required climbs/descents;	Apply	Support
Monitoring conformance of aircraft to planned trajectory;	Apply	Support
Identifying conflicts,	Apply	Support
Monitoring evolution of conflict solution;	Apply	Support
Identifying opportunities for improvement of quality of service;	Apply	Support
Identifying missing information needed to solve a problem;	Apply	Support
Identifying aircraft with possible equipment degradation;	Apply	Support
Monitoring adverse weather areas and restricted airspace.	Apply	Support
Identifying workload with specific aircraft according to companies and pilots expected behaviour	Apply	Support
Monitoring of the status and performance of ATC sub-systems	Apply	Support

Table 9 Role distribution between ATCOs and AI

5.2.1.5 Prioritizing the ATC tasks

Even among the monitoring tasks, it is useful to make a prioritisation to show which are the ones to start the AI introduction to ATM. This priority list can be useful at the AISA concept level in terms of the road towards AI SAS, but also in the project level as it is a direct input to the AI SAM development.

The AISA consortium with the active involvement of air traffic controllers did the initial prioritization of the different tasks in terms of suitability for AI support provision and team situational awareness among human and system. The three main criteria in the selection were the following:

- Possible impact on safety as AI implementation bears a certain risk as discussed earlier,

- Suitability for an early AI implementation,
- Suitability to demonstrate Team situational awareness among machine and human.

The air traffic controllers focused first on the safety aspects. They chose tasks for early AI adaption which are:

- Non-safety critical information monitoring: they would like to avoid using a safety-critical decision support type of system monitoring provided to ATCOs when ATCOs rely upon/trust such info, there is a (potentially negative) consequence to it,
- Focus on the quality of air traffic navigation services: the service the system generates have fallen into the "nice to have" category.

5.2.1.6 The Selected AISA tasks

Based on the analysis and the validation by experts as presented in section 4.3 and section 5.2.1.5, the following is the initial list of ATCO related tasks where the future AISA system should provide AI-backed support service:

- identifying opportunities for improvement of quality of service,
- monitoring adverse weather areas and restricted airspace,
- identifying aircraft with possible equipment degradation,
- identifying workload (e.g. additional attention, care) that are specific to companies and pilots expected behaviours,
- monitoring of the status and performance of ATC sub-systems.

This list shows only with what kind of tasks it is advised to start the AI implementation to ATC tasks under the current knowledge of the AISA consortium and the ATC experts. If tests and experience with these tasks are closed with a positive result, gradual progress towards other ATC tasks can be made.

5.3 Guidelines for functional requirements

5.3.1 General provisions

As mentioned in the methodologies section, the functional requirements at the AI SAS level are not meant to be full and complex as a high level of change is expected both in the working environment and in the technology until the adaption of an AISA type of solution. As a TRL-1 project, AISA is not meant to deal with certain implementation type of requirements.

Notwithstanding, AISA would like to support any subsequent activities to give guidance on how functional requirements should be built and what are the ATC tasks to start the process with.

5.3.2 Main input and output categories

The AI SAS shall be able to receive inputs from and to give outputs to the following main external entity categories:

- ATCOs
- Pilots

- System engineers
- Other systems
- Databases.

It is important to mention that AI systems usually work in the background, so the interaction with them is made via other system layers. In the case of AISA, through the main ATC system HMI and the relevant intermediate layers for other systems and databases.

5.3.3 Functional requirements examples

5.3.3.1 Detailed requirement examples for the selected tasks

As mentioned in section 4.2.1.6 the initial task list to which functional requirements are needed is the following:

- identifying opportunities for improvement of quality of service
- monitoring adverse weather areas and restricted airspace
- identifying aircraft with possible equipment degradation
- identifying workload (e.g. additional attention, care) that are specific to companies and pilots expected behaviours
- monitoring of the status and performance of ATC sub-systems.

In the following table, one example of a possible requirement is mentioned for each selected task for AI SAS activities. However, it is important to mention, highlight again, that these sub-tasks, scenarios are just one among many other possibilities still to be explored by subsequent research and development activities. A more detailed list of requirements for the tasks that are planned to be achieved during the project is given in Section 6. That list however is guided more by the goals of the exploratory research and less by the expected importance of introducing automation for the specific tasks.

Req. ID	Task	Description	Input	Output
FR_REQ1	Monitoring and prediction of adverse weather areas (CB, Turbulence) and restricted airspace (MIL on/off, GA active areas)	The system should inform ATCOs on its findings in case of likely adverse weather in their sectors. Examples of such info could be against: Flight level, Routing, Aircraft type, Airline, Suggestion of re-routing, alternative Flight level.	Historic weather information data set, sector territory, current weather information, weather forecast information, pilots report, aircraft system weather data (downlinked via FMS) such as wind, airborne WX radar, etc.	Forecasted likely adverse weather anomaly warning, specific indication of weather phenomena

FR_REQ2	Identifying opportunities for improvement of quality of services	The system should suggest direct routings, optimum flight level and routing (conflict-free) for more than one unit (here unit means ACC – ACC, ACC– APP, ACC – Lower airspace (for regional aerodrome), and when possible (via e-coordination/SWIM) adjacent ANSPs	4D trajectory data Aircraft performance data (beyond ECTL BADA but more accurate/real-time) Procedures Live status of sectors and aerodromes combined with WX data	The optimized trajectory in a more broad-spectrum view (e.g. could be shown on the wall screen as an idea besides the individual screen, etc.)
FR_REQ3	Identifying aircraft with possible equipment degradation	The system should identify and report equipment degradation. It displays the remaining performance and manoeuvring capabilities.	FMS and airborne system status (via downlinked to ATC system on the ground by updating/overruling FPL data/processing system	Detection and indication of possible emergency (by the system) and contingency scenario. Current status indication of the airborne system.
FR_REQ4	Identifying workload (e.g. additional attention, care) that are specific to companies and pilots expected behaviours	The system should inform ATCOs with pilots' or company-specific information and expected behaviours (based on past preferences, events or company policy, etc)	Company-specific policy, rules, procedures Pilots past requests, preferences ATCO's experiences	Optimized trajectory planning Awareness of specific expected/preferences for better anticipation, planning
FR_REQ5	Monitoring ATM system	The system should support ATCOs with status and quality of the ATC ground systems and tools and shows remaining performance capabilities, manoeuvring capabilities (e.g. traffic saturation of adjacent sectors, units, ANSPs, departure/arrival delays of airports, CPDLC coverage status, DF signal strength, etc)	Various ATC specific equipment (e.g. traffic prediction tool, CNS system status, Radar/flight data processing system, CDM data, etc)	Detection and indication of the real-time status of various units/airports/centres. It also shows alternative means/plans/possibilities (e.g. which sector/FL or routing is still available, etc)

Table 10 Requirements for each task

5.3.3.2 Machine Learning related conceptual requirements

As described in the AISA architecture section (chapter 2.2.2), the machine learning module is an important part of the concept, therefore, it is useful to set the related requirements. However, as mentioned above, the requirements below should be considered as examples only.

Req. ID	Description
MLCR1	ML module should provide meta-data regarding the training set used for training.
MLCR2	ML module should be able to provide outputs in a standard data exchange format.
MLCR3	ML module should have a self-test function which would ensure early detection of performance degradation.
MLCR4	ML module should present predictions based on high-rates of accuracy and reliability (e.g., low false positive and negative rate).
MLCR5	ML module should be able to provide information about the uncertainty in the predictions.

Table 11 Requirements for Machine Learning module

5.3.3.3 Conceptual requirements regarding Knowledge Engineering

An important part of the AI SAS is the knowledge graph (KG) and reasoning engine. It is, therefore, useful to set the requirements regarding knowledge engineering.

Req. ID	Description
KGCR1	Extensibility: The AI SAS should enable to incrementally add new types of knowledge to the KG not considered previously to increase the capability of KG and reasoning system (e.g., additional weather forecasts)
KGCR2	Flexibility: The reasoning engine should be able to fulfil unforeseen requirements regarding the expressiveness of rule representation.
KGCR3	Adherence to information exchange models: To support semantic interoperability, the schema of the KG should adhere as much as possible to established information exchange models (e.g., AIXM, FIXM).
KGCR4	Standard-adherence: The system should use open standards, such as RDF for knowledge representation in the KG
KGCR5	Integrity checking: The KG system should support checks for data integrity, i.e., if data conform to pre-defined constraints
KGCR6	Ad-hoc Querying: The system should facilitate the formulation of non-canned, ad hoc queries to KG
KGCR7	Usability and Maintainability: The system should support the definition of user views providing problem-specific perspectives on the KG facilitating query/rule formulation and maintenance

Table 12 Requirements for Knowledge Engineering

6 Project level requirements

A more project-specific approach is presented in this section, whereas a more general, higher-level requirements for the AISA system were given in the previous sections. **This section aims to provide a single point of reference in terms of requirements needed to achieve the project goals and, therefore, maps directly to Section 5 of the project ConOps**. As previously mentioned, the scope of the project is much narrower, by design, than the scope of all possible future applications of AISA.

In this project, AISA architecture is based on two main parts: knowledge graph with reasoning engine and machine learning modules. The knowledge graph is used to store all knowledge necessary to perform monitoring tasks. The reasoning engine is used to reason over the facts stored in the knowledge graph. Machine learning (ML) modules perform those tasks that cannot be calculated directly or cannot be inferred from the existing knowledge in the knowledge graph, i.e. predictions and estimates. Since there are three ML modules to be tested in this project, each will have its requirements defined. All these parts together make a proof-of-concept KG-based system whose conceptual diagram is visible in Figure 2.

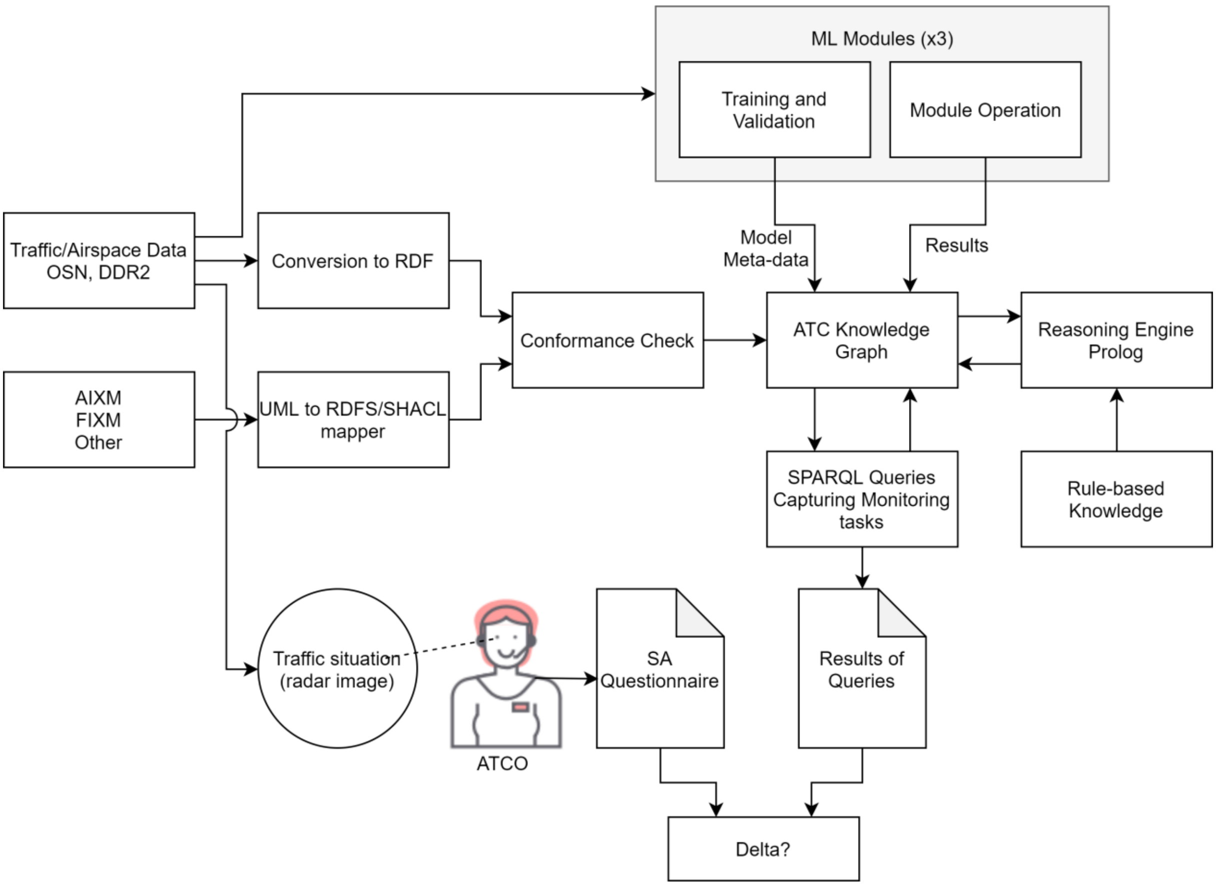

Figure 2 Conceptual diagram of a Proof-of-Concept Knowledge-based System

The requirements are also presented for a selected set of monitoring tasks which are deemed to be possible to automate in the early stages of AISA development. For each of the tasks, a list of input information, processing requirements, and expected outputs is provided.

Also, it is important to mention that the concept level requirements (e.g. the ones listed in the previous chapter) are also relevant at project level, but with the obvious adoption to the project's needs. The project is an experimental one, therefore the concept level requirements serve as a menu from which subsequent technical work packages (especially WP3 and WP4) modelling machine learning and reasoning engine should select the applicable ones necessary to conduct their exercises and should take them into account to the level necessary for the execution of the certain experiment.

6.1 Requirements for Knowledge Graph and Reasoning Engine

Knowledge graphs (KGs) are large collections of facts. Knowledge graph systems can build on the rich set of semantic web standards and related tools which provide a high degree of interoperability and make it comparably easy to integrate data and knowledge from diverse sources. RDF with its simple data model (every fact is a subject-predicate-object triple), its various data formats (RDF/XML, Turtle, JSON-LD), and its rich set of data types from XML Schema is used to encode factual knowledge and to organize this knowledge in a set of named graphs. IRIs as object identifiers and basic web technologies (HTTP) facilitate distribution and decentralization. free open-source software packages are available for all these technologies.

Ontologies in OWL or RDF schema specify the semantics of classes and properties in vocabulary and let the reasoner and the SPARQL engine infer additional facts, but they do not provide means to specify structural constraints. For example, in OWL 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.

Req. ID	Description
KGRER1	Classes and properties used in the knowledge graph shall be defined using RDF Schema (RDFS)
KGRER2	KG shall be queried with SPARQL.
KGRER3	Data instances shall be provided in RDF.
KGRER4	SHACL shall be used to check the instance data against the constraints and validation report shall be provided in RDF.

Table 13 Requirements for Knowledge Graph and Reasoning Engine

Building on our previous experience from 'BEST' project, we will develop a mapping from UML class diagrams to vocabulary in RDFS and structural constraints in SHACL. The RDFS vocabulary may be generated as a lightweight subset of the OWL ontologies generated in project BEST or differ more substantially. The UML-to-RDFS/SHACL mapper will take, for example, a subset of AIRM as input and produce a corresponding RDFS vocabulary and SHACL constraints. 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).

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 unforeseen requirements might emerge during the project. The versatile tried and tested SWI-Prolog system facilitates such a flexible approach.

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).

6.2 Requirements for UML to RDFS/SHACL Mapper and Proof-of-Concept KG system

Req. ID	Description
UMLR1	Mapper shall process UML class diagrams in XMI format.
UMLR2	Mapper shall process AIXM and FIXM UML diagrams in full.
UMLR3	User should be able to select a subset of AIXM and FIXM to process.
UMLR4	Mapper shall process other UML diagrams (outside of AIXM and FIXM) if provided in the same format as AIXM and FIXM.

Table 14 Requirements for UML to RDFS/SHACL Mapper

Req. ID	Description
KGSR1	Instance data shall be imported into the KG in RDF.
KGSR2	KG shall be queried with SPARQL queries.
KGSR3	KG shall provide RDF graph store.

KGSR4	KG shall provide SPARQL endpoints.
KGSR5	KG shall provide reasoning/entailment over RDF graphs.
KGSR6	KG shall provide SHACL processors for checking conformance between the knowledge graph and the schema and for executing inference rules encoded in SHACL.

Table 15 Requirements for KG-System

Description:

We will develop a UML to RDFS/SHACL mapper which generates from a conceptual schema (UML class diagram in XMI) the knowledge graph's vocabulary (in RDFS) and its schema (structural constraints in SHACL). This task also comprises setting up a proof-of-concept KG system including RDF graph store, SPARQL endpoints, RDFS reasoning/entailment, and SHACL processors for checking conformance between the knowledge graph and the schema and for executing inference rules encoded in SHACL. Data, vocabulary, structural constraints and simple rules will all be stored in the RDF graph store, where different fragments of the data and knowledge may be stored in separate named graphs and be associated with different structural constraints and rules. For demonstrating the mapper and KG system, we will populate the KG by producing RDFS vocabulary and SHACL constraints from a fragment of AIXM, load AIXM data (transformed to RDF beforehand, note: data translators are not part of this task) into the graph store, use the SHACL processor to check conformance to constraints. We will conduct preliminary performance studies to get first insights into the approach's performance characteristics which may guide future work on high performant and highly scalable KG systems which will be necessary for using the approach in a real-life ATC setting.

6.2.1 Requirements for KG-Prolog Mapper

Req. ID	Description
KGPMR1	KG-Prolog mapper shall receive results of the SPARQL queries or complete KG and convert them into predicates.
KGPMR2	Based on the results of the logic programs, mapper shall produce SPARQL update requests.
KGPMR3	Based on the results of the logic programs, mapper shall produce Prolog rules.
KGPMR4	Mapper shall update KG with results of SPARQL update requests and Prolog rules.
KGPMR5	Mapper shall derive shape of predicates (arity and ordering of attributes) not only from validating SHACL properties but also from non-validating properties.

Table 16 Requirements for KG-Prolog Mapper

Description:

We will develop a mapper that translates SHACL shapes, SPARQL queries, and Prolog rules to populate the Prolog predicates from the results of executing the SPARQL queries over the KG. The mapper will further produce SPARQL update requests and associated Prolog rules to update the KG with the extent of predicates derived by logic programs. The approach will build on SWI-Prolog's SPARQL client library. The mapper will derive the shape of predicates (arity and ordering of attributes) not only from validating SHACL properties but also from non-validating properties such as sh:order. We will demonstrate the approach by a small set of logic programs which read from and write to the example KG using the predicates, SPARQL queries and associated rules generated by the KG-Prolog Mapper. Similar to proof-of-concept KG system, we will conduct preliminary performance studies regarding the communication between logic programs and a KG system, the results of which may guide future work on highly performant and scalable solutions.

6.2.2 Requirements for Populating the Knowledge Graph

Req. ID	Description
PKGR1	Populating the KG shall be based on RDFS produced from AIXM, FIXM, ML outputs
PKGR2	Populating the KG should be performed by data translators.
PKGR3	ML outputs and other aeronautical information not contained within the AIXM and FIXM shall be adapted for KG.

Table 17 Requirements for populating the KG

Description:

Based on existing ATM information reference and data exchange models available in UML (such as AIRM, AIXM, FIXM, WXXM) this task will identify and combine the relevant parts into a conceptual schema and use the UML-to-RDFS/SHACL mapper to produce the vocabulary and schema of the KG – this process may be incremental, adding/changing the underlying conceptual model and/or the resulting vocabulary and schema over time. Based on vocabulary and schema, data translators are developed to populate the knowledge graph with aeronautical and other data. ML modules will be adapted as inputs into the KG.

6.2.3 Requirements for Knowledge Engineering for En-route ATC Operations

Req. ID	Description
KEER1	All relevant facts and rules about the en-route ATC operations in a specific airspace shall be provided in the KG.
KEER2	SHACL rules in the KG shall be used to represent simpler rules about ATC operations.

KEER3	Logic programs interfacing with the KG and the KG-Prolog mapper should be used to describe more complex rules.
KEER4	SPARQL queries which can be used to monitor the traffic situation and ATCO status shall be developed.

Table 18 Requirements for Knowledge Engineering for En-route ATC Operations

Description:

After the initial knowledge graph system has been developed and populated, knowledge engineering for en-route ATC operations will begin with the purpose of capturing and encoding all relevant facts and rules about the ATC operations. These facts and rules will be gathered by interviews with licenced ATCOs and other ATC-related personnel. Depending on their complexity, the rules will be represented directly in the knowledge graph as SHACL rules or in separate logic programs interfacing with the KG using the KG-Prolog mapper. Furthermore, SPARQL queries which can be used to monitor the traffic situation and ATCO status will be developed and validated.

6.3 Requirements for Machine Learning Modules

6.3.1 Trajectory Prediction Module

In general, upcoming flights are planned and the general structure of the route is known by the filed flight plan before the flight. Nevertheless, delays at departure and delays resulting out of adverse weather occur. Furthermore, pilots request directs to future waypoints by skipping some upcoming waypoints from the flight plan. And finally, re-routings occurs in case of adverse weather or to avoid conflicting situations in congested traffic areas. As a result, the actual flown trajectory may differ from the previously filed flight plan. This uncertainty between the planned trajectory and actual flown trajectory shall be addressed in the trajectory prediction module of task 3.1.

Because of the ML part, it is expected that the module needs to be trained on a specific situation, naming a specific airspace with a certain set of flights occurring within it. Thus, for both, training and operation of the system appropriate input data, at least flight plans and ADS-B data will be required. Flight plans shall be on the same update state (e.g. pre-flight) for training and operation to archive best results. Today, filed flight plans are already available and these should meet the requirements of the module to conduct the task. Analysis of ADS-B data obtained from The OpenSky Network indicated some issues regarding erroneous data and the reliability and completeness of trajectories. In future operations of the AISA system, we assume reliable, accurate and complete ADS-B data regarding the aircraft considered. This requirement leads to a potential pre-filtering of ADS-B data prior to the AISA system at the current state. This pre-filtering will not be part of the AISA system itself. Incomplete input data during training may lead to unexpected behaviour of the ML module and, therefore, training shall be conducted only on complete datasets.

Additionally, to the trajectory input data (flight plans and ADS-B data), weather data may enhance the potential of the trajectory prediction module. In case weather data is going to be used in the AISA system, it will be considered as complete and valid within the trajectory prediction module, too.

In the first phase, static trajectory prediction before the flight shall be considered to predict changes to the filed flight plan learned from flights in the past. At this point, weather data may also be used, but only static information before the flight is required. In the second phase, trajectory prediction may be updated during the flight being conducted, whereof further requirements regarding the actual aircraft state obtained from ADS-B and the current weather situation arise.

Req. ID	Description
TMLR1	The module shall receive input information from the KG.
TMLR2	The module shall provide output information in a standardized format that can be exported to the KG.
TMLR3	The module shall provide KG with model meta-data.
TMLR4	The module shall use flight plans at a common state, e.g. last state before take-off for both training and operation.
TMLR5	The module shall use last known aircraft position for operation.
TMLR6	The module shall use weather data if possible.
TMLR7	The module shall provide trajectory prediction as a set of 4D points.

Table 19 Trajectory Prediction ML Module requirements

6.3.2 Conflict Detection Module

Conflict detection has been studied as a crucial aspect for safety because of the necessity to keep a sufficient level of safety in the airspace. Conflict is a barrier prior to the accident of two aircraft in the airspace. ICAO defines conflict as any situation involving aircraft and hazards in which the applicable separation minima may be compromised. ATM community is evolving to use the term called potential conflict as those trajectories for which the future position of 2 or more aircraft might fall below specified minima (not necessary the separation minima). In addition, aircraft of interest are an aircraft pair that the ATC must pay attention to because their trajectories are expected to cross below specified minima (similar to potential conflict). As the three terms are quite similar, in the project they could be exchanged.

Currently, the Air Traffic Controllers (ATCOs) can evaluate conflicts by themselves analysing the predicted trajectories showed in the Sector Control Unit (SCU). The SCU shows the relative position of the aircraft and they can estimate if a conflict could occur based on their previous knowledge of the aircraft evolution. To facilitate the conflict-search task, a ground server evaluates the trajectories in order to detect conflicts between an aircraft pair based on their current position and predicted trajectory. Typically, the way it is calculated is transparent for the ATCO and it could be by using different mathematical techniques such as static models, worst-scenario or probabilistic. In the case a conflict is detected by the ground server, it notifies the ATCOs this situation. Then, the ATCO analyses the situation and solves the conflict by acting on the aircraft with different measures depending on the situation.

The approach we develop in this module is to assess the feasibility of using ML techniques for conflict detection. The output of this task will be similar to the one described above but using new mathematical techniques. The approach tackles two modes. Mode one focuses on a static prediction of the conflict detection once the aircraft pierces into the airspace. This static conflict prediction addresses to the planner controller role. Mode two focuses on a dynamic prediction of the conflict throughout the evolution of the trajectory within the airspace sector. This dynamic conflict prediction addresses to the tactical controller role. Besides, the methodology developed in this module, although it will be applied to a particular en-route scenario, could be implemented to other airspaces.

Req. ID	Description
MLPR1	The module shall receive input information from the KG.
MLPR2	The module shall provide output information in a standardized format that can be exported to the KG.
MLPR3	The module shall provide KG with model meta-data.
MLPR4	ML module should be able to perform prediction exploiting open-access libraries (e.g., Scikit-Learn or Tensor Flow).
MLPR5	ML module shall be able to provide information about conflict or situations of interest between aircraft pairs.
MLPR6	ML module should be able to provide information about safety metrics related to conflict or situations of interest between aircraft pairs.

Table 20 Requirements for Conflict Detection module

6.3.3 Air Traffic Complexity Estimation Module

The purpose of this module is to show that a level of situational awareness regarding the state of the ATCOs is achievable by using ML. The approach we take here is to assess the air traffic complexity as a proxy measure of ATCO workload. Air traffic complexity has been a common research topic since the early days of modern air traffic control (ATC) operations. In the beginning, most of the research was dealing with the air traffic controller (ATCO) workload instead of air traffic complexity to express how difficult some ATCO tasks were. Because of that, it is important to explain the relation between these two indicators. The first papers that deal with complexity were written in the early 1960s. Since then, numerous papers and reports have been written on the topic of complexity. They concluded that the air traffic complexity is a fundamental driver of workload, but that the connection between complexity and workload is not straightforward; it is mediated by other factors, such as equipment quality, individual differences, and controller cognitive strategies.

Today, ATM experts still use air traffic controllers' subjective assessment as the most important method for determining air traffic complexity, even though many studies have dealt with the development of new, more objective methods for determination of air traffic complexity. In this module, however, a mathematical model for air traffic complexity which is based on the air traffic controller tasks is used.

The air traffic controller's tasks are defined based on characteristics of the air traffic situation and do not depend on the person controlling the air traffic. Because of this, by defining a set of air traffic controller tasks based on the pre-conflict resolution parameters, the model could calculate adequate complexity score. The tasks so defined could apply to other airspaces and would not be tied to the specific air traffic controller. Additionally, to ensure the possibility that the model could be used on different airspaces, traffic situations were defined on a generic airspace to avoid air traffic controller subjective assessment for the already known traffic situations and airspaces. Using machine learning, inputs such as defined air traffic controller tasks and data gained through this method are used to develop a new mathematical model for determining air traffic complexity.

Req. ID	Description
TCER1	The module shall receive input information from the KG.
TCER2	The module shall provide output information in a standardized format that can be exported to the KG.
TCER3	The module shall provide KG with model meta-data.
TCER4	The module shall provide sector-level air traffic complexity score on a scale from 1 to 5.

Table 21 Air Traffic Complexity Estimation Module Requirements

6.4 Requirements for Automation of Monitoring Tasks in Proof-of-Concept System

In this section, a list of the monitoring tasks deemed ready for automation via AISA at the current state of development is presented. By its nature, the description of the task is also a system requirement because the system needs to be able to perform the task for it to be declared as automated. These automation tasks do not represent a comprehensive list of all possible tasks that could be automated if the development of AISA continues. Prerequisites for the automation of monitoring tasks is that the KG system is developed to a level that includes all necessary knowledge and rules. Certainly, **only a subset of these monitoring tasks will be tested during the project**. However, these tests will provide the necessary feedback and insights into the benefits and drawbacks of the proposed architecture.

Tasks	Requirements
1. Conformance management	The system shall use existing classes and properties to infer new knowledge. The system shall return all newly inferred knowledge back into the KG as new property values.
1.1. Check that aircraft is Climbing/descending towards cleared FL 1.2. Check that aircraft is at cleared FL 1.3. Check that aircraft is maintaining FL	CMR1.1 The system shall infer whether the aircraft is approaching (by climbing/descending) the cleared FL. CMR1.2 The system shall infer whether the aircraft is at cleared FL. CMR1.3 The system shall infer whether the aircraft is maintaining the FL

1.4. Check that aircraft is turning towards/opposite of cleared heading	CMR1.4 The system shall infer whether the aircraft is turning towards the cleared heading.
1.5. Check that aircraft is at cleared heading	CMR1.5 The system shall infer whether the aircraft is at cleared heading.
1.6. Check that aircraft is maintaining current heading (different than cleared heading)	CMR1.6 The system shall infer whether the aircraft is maintaining the current heading.
1.7. Check that aircraft is accelerating/decelerating towards cleared speed	CMR1.7 The system shall infer whether the aircraft is approaching (by accelerating or decelerating) the cleared speed.
1.8. Check that aircraft is flying at cleared speed	CMR1.8 The system shall infer whether the aircraft is flying at cleared speed.
1.9. Check that aircraft is maintaining current speed (different than cleared speed)	CMR1.9 The system shall infer whether the aircraft is maintaining the current speed.
1.10. Check that aircraft is flying towards cleared point	CMR1.10 The system shall infer whether the aircraft is flying towards the cleared point.
1.11. Check that aircraft is at cleared point	CMR1.11 The system shall infer whether the aircraft is at cleared point.
1.12. Check that aircraft's current ROC/ROD is lower/higher than cleared	CMR1.12 The system shall infer whether the aircraft is climbing or descending with greater or lower rate than cleared.
1.13. Check that aircraft is maintaining cleared ROC/ROD	CMR1.13 The system shall infer whether the aircraft is maintaining the cleared ROC/ROD.
1.14. Check that aircraft is increasing/decreasing towards cleared ROC/ROD	CMR1.14 The system shall infer whether the aircraft is increasing/decreasing the rate at which it is approaching the cleared ROC/ROD.
1.15. Check that aircraft is following the 3D trajectory	CMR1.15 The system shall infer whether the aircraft is following the negotiated 3D trajectory.
1.16. Check if the deviation from 3D trajectory is within tolerance	CMR1.16 The system shall infer whether the deviation that the aircraft made from the negotiated 3D trajectory is within the tolerance.
1.17. Check that aircraft is following the 4D trajectory	CMR1.17 The system shall infer whether the aircraft is following the 4D trajectory.
1.18. Check if the deviation from 4D trajectory is within tolerance	CMR1.18 The system shall infer whether the deviation that the aircraft made from the negotiated 4D trajectory is within the tolerance.
2. Detect Incoming Planned Flights	
2.1. Check that aircraft is close to Sector boundary	DIPR2.1 The system shall infer whether the aircraft is close to the sector boundary.
2.2. Check that aircraft is approaching Sector boundary	DIPR2.2 The system shall infer whether the aircraft is approaching the sector boundary.

2.3. Check that aircraft's altitude is within the altitude band of the Sector	DIPR2.3 The system shall infer whether the aircraft's altitude is within the altitude band of the Sector.
2.4. Check that aircraft's altitude is approaching the Sector altitude	DIPR2.4. The system shall infer whether the aircraft's altitude is approaching the altitude of the Sector.
3. Assume, Identify, and Confirm Flight	
3.1. Check that aircraft is incoming	AICR3.1 The system shall infer whether the aircraft is incoming
3.2. Check that aircraft is planned	AICR3.2 The system shall infer whether the aircraft is planned.
3.3. Check that aircraft has sent the initial call (via datalink)	AICR3.3 The system shall infer whether the aircraft has sent the initial call.
3.4. Confirm that aircraft can be assumed	AICR3.4 The system shall infer whether the conditions have been met for the aircraft to be assumed.
4. Assess if Exit Conditions are Met	
4.1. Check that aircraft is flying towards the exit point	AEC4.1 The system shall infer whether the aircraft is flying towards the exit point.
4.2. Check that aircraft will reach the exit point on the required FL	AEC4.2 The system shall infer whether the aircraft will reach the exit point on the required FL.
4.3. Check that aircraft will reach the exit point at the expected time	AEC4.3 The system shall infer whether the aircraft will reach the exit point at the expected time.
5. Conflict Management	
5.1. Check all aircraft pairs for conflict (ML module) 5.2. Check plausibility of the predicted conflicts 5.3. Check which conflicts are to occur within the sector 5.4. Rank conflicts based on urgency	CFMR5.1a The system shall sequentially select an aircraft pair from a list of aircraft pairs and send their data to the conflict detection ML module. CFMR5.1b The system should use other available data to prioritize checking an aircraft pair which has higher probability of being in conflict. CFMR5.1c The system shall integrate the results of the ML module into the KG noting the provenance of the results. CFMR5.2a The system shall infer whether the data provided as input to the ML module is in line with the data used for model training. CFMR5.2b The system shall check the plausibility of the ML module's results by running the results against the known facts and rules. CFMR5.2c The system shall keep track of the ML module's results over time to determine the accuracy of the module. CFMR5.3 The system shall infer whether the conflict will occur within the sector. CFMR5.4 The system shall rank conflicts based on urgency by taking time to conflict into account.
6. Execute Aircraft's Plan	

6.1. Detect aircraft that have to climb/descend to requested FL 6.2. Detect aircraft that have to climb/descend to exit FL 6.3. Detect aircraft that will reach top of descent within the Sector (ML module) 6.4. Detect if planned trajectory passes through restricted airspace	EAPR6.1 The system shall infer whether the aircraft has to climb/descend to reach its requested FL. EAPR6.2 The system shall infer whether the aircraft must climb/descend to reach its exit FL. EAPR6.3a The system shall sequentially select each aircraft and send its data to the trajectory prediction ML module to check whether its top of descent is situated within the sector. EAPR6.3b The system should use inference over other available knowledge to determine if the check needs to be performed. EAPR6.3c The system shall integrate the results of the ML module into the KG noting the provenance of the results. EAPR6.4 The system shall infer whether the aircraft's trajectory passes through the restricted airspace. EAPR6.5 The system shall infer whether the data provided as input to the ML module is in line with the data used for model training. EAPR6.6 The system shall check the plausibility of the ML module's results by running the results against the known facts and rules. EAPR6.7 The system shall keep track of the ML module's results over time to determine the accuracy of the module.
7. Transfer Aircraft	
7.1. Check which aircraft need to be transferred 7.2. Check if change of frequency is issued to A/C (via datalink) 7.3. Change aircraft status to transferred	TAR7.1 The system shall infer whether the aircraft needs to be transferred based on the knowledge in KG and rules. TAR7.2 The system shall infer whether the change of frequency was issued to the aircraft. TAR7.3 The system shall infer whether the aircraft's status can be changed to transferred and do so if it can.
8. Maximise Quality of Service	
8.1. Detect direct-to candidates 8.2. Determine military airspace availability 8.3. Check suggestion for shortened RBT	MQSR8.1a The system shall infer whether the aircraft can be given a direct course towards the exit point. MQSR8.1b The system should trigger conflict detection module for the proposed direct-to course before suggesting change in routing. MQSR8.2 The system should infer whether the aircraft can use previously reserved military airspace. MQSR8.3 The system will check whether the suggested shortened RBT causes conflicts.
9. Workload Monitoring	

9.1. Track current number of assumed aircraft 9.2. Track number of conflicts and potential conflicts 9.3. Determine future number of sector entries	WMR9.1 The system shall track the number of assumed aircraft over time. WMR9.2a The system shall track the number of conflicts and potential conflicts over time. WMR9.2b The system should keep track of conflict-solving manoeuvres and their effectiveness. WMR9.3a The system shall activate the ML module for trajectory prediction in order to determine the number of future sector entries. WMR9.3b The system shall also determine the number of future sector entries via flight plans, RBTs and simple vector extrapolation.
9.4. Determine sector air traffic complexity (ML module) 9.5. Determine plausibility of traffic complexity assessment	WMR9.4a The system shall select needed data and send it to complexity assessment ML module. WMR9.4b The system shall infer whether the data provided as input to the ML module is in line with the data used for model training. WMR9.4c The system shall integrate the results of the ML module into the KG noting the provenance of the results. WMR9.5 The system shall check the plausibility of the ML module's results by running the results against the known facts and rules.
10. Identify Missing Information	
10.1. Identify aircraft with possible equipment degradation 10.2. Check situation at destination airport 10.3. Check situation at alternate airports 10.4. Monitor adverse weather areas 10.5. Monitor restricted airspace 10.6. Infer missing information	IMIR10.1a The system shall identify aircraft actively announcing equipment failure. IMIR10.1b The system shall check plausibility of the data received from the aircraft in order to detect possible equipment degradation. IMIR10.2 The system should check situation at the destination airport. IMIR10.3 The system should check situation at alternate airports. IMIR10.4 The system shall include adverse weather areas into decision-making. IMIR10.5 The system shall include restricted airspace into decision-making. IMIR10.6a The system shall infer whether the particular information that should be transferred via AIXM/FIXM is missing. IMIR10.6b The system shall check if any of the information is outside standard constraints as determined in the exchange model's specification.
11. Monitor Status of ATC Sub-systems	

11.1. Monitor performance of ATC conflict detection module 11.2. Monitor performance of complexity assessment module 11.3. Monitor performance of trajectory prediction module	MSR11.Xa The system shall infer whether the data provided as input to the ML module is in line with the data used for model training. MSR11.Xb The system shall integrate the results of the ML module into the KG noting the provenance of the results. MSR11.Xc The system shall check the plausibility of the ML module's results by running the results against the known facts and rules.

Table 22 Requirements for Automation of Monitoring Tasks in Proof-of-Concept System

7 References

[1] AISA, “AISA D2.1 Concept of Operations for AI Situational Awareness System”.

[2] AUTOPACE, “AUTOPACE D2.1 Future Automation Scenarios”.

[3] “D5.1 AUTOPACE,” AUTOPACE Project.

[4] E. 3, “EPISODE 3: Today's Operations Task Analysis - Human Factor Assesment”.

[5] J. García, “AI current research and challenges. Applicability to ATM automation,” p. 24.

[6] E. HLG, “Fly AI Report - Demystifying and Accelerating AI in Aviation/ATM,” 2020.

[7] R. D. Gilson, D. J. Garland and J. M. Koonce, “Situational awareness in complex systems,” 1994..

[8] A. HLEG, “Ethics Guidelines for a Trustworthy AI”.

Appendix A Glossary

Abbreviation	Description
CPDLC	Controller Pilot Data Link Communications
ACC	Area Control Center
CNS	Communications, Navigation and Surveillance Systems
AB	Advisory Board
AI	Artificial Intelligence
AI HLEG	High-Level Group on Artificial Intelligence
AI SAM	AI Situational Awareness Model
AI SAS	AI Situational Awareness System
AIRM	Air traffic management information reference model
AIXM	Aeronautical Information Exchange Model
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATM	Air Traffic Management
BADA	Base of Aircraft Data
CA	Consortium Agreement
CB	Cumulonimbus
ConOps	Concept of Operations for AI Situational Awareness System
DCE	Dissemination, Communication, Exploitation
DoA	Description of Action
E-FP	Electronic Flight Plan
E-FS	Electronic Flight Strip
FAQ	Frequented Asked Questions
FIXM	Flight Information Exchange Model
FPS	Flight progress strip
GA	Grant Agreement
HMI	Human Machine Interface
HTTP	Hypertext Transfer Protocol
iFMP	integrated Flow Management Position
IPR	Intellectual Property Rights

KG	Knowledge Graph
KPI	Key Progress Indicator
ML	Machine Learning
MLCR	Machine Learning related conceptual requirements
OOTL	Out-of-the-loop
OPR	Operation related requirements
OWL	Web Ontology Language
RBT	Reference Business Trajectory
RDFS	Resource Description Framework (RDF) Schema
ROC	Rate of Climb
ROD	Rate of Descent
RPVD	Radar Plan-View Display
SA	Situational Awareness
SHACL	Shapes Constraint Language
SPARQL	Protocol and RDF Query Language
TRL	Technology Readiness Level
TSAR	Team Situational Awareness Requirement
UML	Unified Modeling Language
WP	Work Package
WXXM	Weather Information Exchange Model
XML	Extensible Markup Language

Table 1 Table of acronyms

Term	Definition
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
AI Situational Awareness Model	The model developed within AISA and which represents such core functions of the future system (AI SAS) which is relevant for the project

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 Traffic Control	1. Air Traffic Control's principal purpose is to maintain sufficient separation between aircraft and between aircraft and obstructions on the ground to avoid collisions. 2. A service operated by appropriate authority to promote the safe, orderly and expeditious flow of air traffic.
Air Traffic Control Officer	1. 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. 2. An air traffic controller, qualified following Annex 1 — Personnel Licensing, and holding a rating appropriate to the assigned functions. 3. A person authorized to provide air traffic control services.
Air Traffic Management	1.ATM is covering all the activities involved in ensuring the safe and orderly flow of the air traffic. It comprises three main services – Air Traffic Control (ATC), Air Traffic Flow Management (ATFM) and Airspace Management (ASM). 2. The aggregation of the airborne and ground-based functions (air traffic services, airspace management and air traffic flow management) required to ensure the safe and efficient movement of aircraft during all phases of operations. 3. 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
Air traffic management information reference model	ATM system-wide reference vocabulary for defining ATM information. The AIRM captures terms and definitions from an agreed set of ICAO annexes and documents, as well as from global information exchange models such as the Aeronautical Information Exchange Model (AIXM), the Flight Information Exchange Model (FIXM), and the ICAO Meteorological Information Exchange Model (IWXXM).
Area Control Center	A unit established to provide air traffic control service to controlled flights in control areas under its jurisdiction
Artificial Intelligence	Intelligence demonstrated by machines.

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.
Concept of Operations for AI Situational Awareness System	A document that will be the 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.
Controller Pilot Data Link Communications	A means of communication between controller and pilot, using data link for ATC communications.
Cumulonimbus	Cumulonimbus is a heavy and dense cloud of considerable vertical extent in the form of a mountain or huge tower, often associated with heavy precipitation, lightning and thunder.
Extensible Markup Language	A markup language that defines a set of rules for encoding documents in a format that is both human-readable and machine-readable.
Flight Information Exchange Model	A data interchange format for sharing information about flights throughout their lifecycle.
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.
High-Level Group on Artificial Intelligence	The High-Level Expert Group on Artificial Intelligence (AI HLEG) has as a general objective to support the implementation of the European Strategy on Artificial Intelligence. This includes the elaboration of recommendations on future-related policy development and on ethical, legal and societal issues related to AI, including socio-economic challenges.
Human Machine Interface	A feature or component of a certain device or software application that enables humans to engage and interact with machines.
Hypertext Transfer Protocol	the set of rules for transferring files, such as text, graphic images, sound, video, and other multimedia files, on the World Wide Web.

integrated Flow Management Position	The iFMP features an intuitive, state-of-the-art user interface designed to improve the planning and execution of daily operations. To provide users with more accurate traffic predictions and powerful ATFCM tools, it merges data from a wide range of sources. It has been in operational use at the Maastricht Upper Area Control Centre (MUAC) since February 2015 and became the primary Air Traffic Flow and Capacity Management (ATFCM) decisionmaking tool in April 2016.
Intellectual Property Rights	The rights given to persons over the creations of their minds. They usually give the creator an exclusive right over the use of his/her creation for a certain period of time.
Key Progress Indicator	1.A clearly defined measurement indicator considered to be of the highest importance for measurement in validation exercises and used for validation assessment. 2.[performance indicator] Current/past performance, expected future performance (estimated as part of forecasting and performance modelling), as well as actual progress in achieving performance objectives is quantitatively expressed by means of indicators (sometimes called key performance indicators, or KPIs).
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.
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.
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
Protocol and RDF Query Language	A semantic query language for databases able to retrieve and manipulate data stored in Resource Description Framework (RDF) format.
Resource Description Framework (RDF) Schema	A set of classes with certain properties using the RDF extensible knowledge representation data model, providing basic elements for the description of ontologies, otherwise called RDF vocabularies, intended to structure RDF resources.

Shapes Constraint Language	A language for describing and constraining the contents of RDF graphs. SHACL groups these descriptions and constraints into "shapes", which specify conditions that apply at a given RDF node.
Team	A team is a group of RE, RP, automation and AI working together to achieve the shared SA, etc.
Technology Readiness Level	A method for understanding the maturity of a technology during its acquisition phase. TRLs allow engineers to have a consistent datum of reference for understanding technology evolution, regardless of their technical background.
Unified Modeling Language	A general purpose modelling language. The main aim of UML is to define a standard way to visualize the way a system has been designed. UML is not a programming language, it is rather a visual language.
Weather Information Exchange Model	The Weather Information Exchange Model specifications support the data-centric environment. It supports MET information collection, dissemination and transformation throughout the data chain. It was designed to enable a platform independent, harmonized and interoperable meteorological information exchange covering all the needs of the air transport industry.
Web Ontology Language	A Semantic Web language designed to represent rich and complex knowledge about things, groups of things, and relations between things. OWL is a computational logic-based language such that knowledge expressed in OWL can be exploited by computer programs, e.g., to verify the consistency of that knowledge or to make implicit knowledge explicit.
Work Package	A group of related tasks within a project. Because they look like projects themselves, they are often thought of as sub-projects within a larger project.

Table 2 Table of definitions

Appendix B Requirements for Knowledge Engineering of Selected ATCO Tasks

For each task, a list of requirements is provided. First, each monitoring task is broken down into smaller tasks (also called atomic tasks) that are at a level of detail which enables direct knowledge engineering. However, for a monitoring task selected it could happen that not every atomic task will be tested during the project. This approach is taken because usual task descriptions are too broad and rely on assumed common knowledge. It is important to notice that the overall task (e.g. conflict management) can be made of monitoring subtasks and other subtasks (e.g. analysis, action implementation etc). In this document, only the monitoring part will be considered and even so, not all subtasks will be implemented during this project.

Second, for each task, a required input is given. Some required inputs are based on the exchange models (e.g. AIXM, FIXM) and for those tasks specific structure is mentioned in parentheses (e.g. *EnRoute* or *CoordinationStatus*). Some inputs are provided by outputs of other monitoring tasks and for those, a reference code is provided (e.g. 1.9). This serves as a link between the tasks and shows interdependencies among the atomic tasks and between atomic tasks and other groups of tasks. Some tasks require inputs from the previous time step and for those, a copy of the previous version of KG will be kept.

Next, for each task, a processing layer is provided. Some tasks are achieved by querying the KG, some tasks are using the calculation layer, whereas some tasks require input from the machine learning module. Calculation layer is used to make simple calculations based on the information provided by the KG because KG has very limited calculation capabilities (e.g. KG can compare two numbers but cannot calculate the distance between two aircraft).

Finally, for each task an output requirement is provided. Outputs can be a single value or multiple values depending on the type of the task. All task outputs are stored in the KG, therefore, available for querying or as an input into other tasks.

Requirement (Task description)	Subtask	Input Req.	Processing Req.	Output Req.
1. CONFORMANCE MANAGEMENT	1.1. Check cleared FL	FIXM (EnRoute)	KG	Cleared FL
Identify the non-conformance by understanding the real-time status of the aircraft. Check if non-conformance is causing a conflict. Ask for	1.2. Check current FL	FIXM (EnRoute)	KG	Current FL
	1.3. Check cleared heading	FIXM (EnRoute)	KG	Cleared heading
	1.4. Check current heading	FIXM (EnRoute)	KG	Current heading
	1.5. Check cleared speed	FIXM (EnRoute)	KG	Cleared speed
	1.6. Check current speed	FIXM (EnRoute)	KG	Current speed

the reason of non-conformance and choose if it can be allowed or correct it by routing or restating the previous instruction.	1.7. Check cleared point	FIXM (EnRoute)	KG	Cleared point
	1.8. Check current position	FIXM (EnRoute)	KG	Current position
	1.9. Check cleared ROC/ROD	FIXM (EnRoute), CPDLC	KG	Cleared ROC/ROD
	1.10. Check current ROC/ROD	FIXM (EnRoute), CPDLC	KG	Current ROC/ROD
	1.11. Check that A/C is Climbing/descending towards cleared FL	1.1., 1.2., 1.10., data from previous time-step	KG, Calculation layer	• A/C is climbing/descending towards cleared FL • A/C is not climbing/descending towards cleared FL
	1.12. Check that A/C is at cleared FL	1.1., 1.2.	KG	• Aircraft is at cleared FL • Aircraft is not at cleared FL
	1.13. Check that aircraft is maintaining FL	1.1., 1.2., previous time-step	KG	• Aircraft is maintaining the cleared FL • Aircraft is maintaining higher FL • Aircraft is maintaining lower FL
	1.14. Check that aircraft is turning towards/opposite of cleared heading	1.3., 1.4., data from previous time-step	KG, Calculation Layer	• Aircraft is turning towards cleared heading • Aircraft is maintaining heading other than cleared heading • Aircraft is maintaining cleared heading • Aircraft is turning opposite of cleared heading
	1.15. Check that aircraft is at cleared heading	1.3., 1.4.	KG	• Aircraft is at cleared heading • Aircraft is not at cleared heading
	1.16. Check that aircraft is maintaining current heading (different than cleared heading)	1.3., 1.4., data from previous time-step	KG, Calculation Layer	• Aircraft is maintaining current heading (other than cleared heading) • Aircraft is not maintaining current heading (other than cleared heading)

	1.17. Check that aircraft is increasing/decreasing towards cleared speed	1.5., 1.6., data from previous time-step	KG, Calculation Layer	• Aircraft is increasing towards cleared speed • Aircraft is maintaining current speed • Aircraft is decreasing towards cleared speed • Aircraft is increasing speed when cleared speed is lower than current • Aircraft is decreasing speed when cleared speed is higher than current
	1.18. Check that aircraft is flying at cleared speed	1.5., 1.6.	KG	• Aircraft is flying at cleared speed • Aircraft is flying at a higher speed than cleared • Aircraft is flying at a lower speed than cleared
	1.19. Check that aircraft is maintaining current speed (different than cleared speed)	1.5., 1.6., data from previous time-step	KG	• Aircraft is maintaining current speed (different than cleared speed) • Aircraft is not maintaining current speed (different than cleared speed)
	1.20. Check that aircraft is flying towards point	1.4., 1.7., 1.8., data from previous time-step	KG, Calculation Layer	• Aircraft is flying towards point • Aircraft is not flying towards point
	1.21. Check that aircraft is at cleared point	1.4., 1.7., 1.8.	KG	• Aircraft is at cleared point • Aircraft is not at cleared point
	1.22. Check that aircraft's current ROC/ROD is lower/higher than cleared	1.9., 1.10.	KG, Calculation Layer	• Aircraft's current ROC/ROD is higher than cleared • Aircraft's current ROC/ROD is lower than cleared • Aircraft is maintaining cleared ROC/ROD

	1.23. Check that aircraft is maintaining cleared ROC/ROD	1.9., 1.10., data from previous time-step	KG	• Aircraft is maintaining cleared ROC/ROD • Aircraft is not maintaining cleared ROC/ROD
	1.24. Check that aircraft is increasing/decreasing towards cleared ROC/ROD	1.9., 1.10., data from previous time-step	KG, Calculation Layer	• Aircraft is increasing towards cleared ROC/ROD • Aircraft is decreasing towards cleared ROC/ROD • Aircraft is maintaining current ROC/ROD • Aircraft is decreasing its ROC/ROD when it should be increasing • Aircraft is increasing its ROC/ROD when it should be decreasing
	1.25. Check that A/C is following the 3D trajectory	data from previous time-step, FIXM (Route), AIXM (Navaids Points), ML module	KG, ML, Calculation layer	• A/C is on the trajectory • A/C is deviating from the trajectory
	1.26. Check if the deviation from 3D trajectory is within tolerance	AIXM (Navaids Points), FIXM (Route), ML module	KG, ML, Calculation layer	• A/C is within tolerance • A/C is deviating from the tolerance
	1.27. Check that A/C is following the 4D trajectory	data from previous time-step, AIXM (Navaids Points), FIXM (Route), ML module	KG, ML, Calculation layer	• A/C is on the trajectory • A/C is deviating from the trajectory
	1.28. Check if the deviation from 4D trajectory is within tolerance	AIXM (Navaids Points), FIXM (Route), ML module	KG, ML, Calculation layer	• A/C is within tolerance • A/C is deviating from the tolerance
2. DETECT INCOMING	2.1. Check A/C location	FIXM (EnRoute), 1.8.	KG	A/C location

PLANNED FLIGHT Initial detection of the aircraft and its plan, system gains knowledge of the aircraft location and planned intentions.	2.2. Check trajectory route display for A/C planned intentions	FIXM (EnRoute)	KG	Trajectory route display
3. ASSUME, IDENTIFY AND CONFIRM AIRCRAFT Receive pilot's incoming report and reply with positive identification and initial clearance if required.	3.1. Monitor incoming traffic	1.8., 1.20., 2.2., FIXM (EnRoute), ML module	KG, ML	Incoming traffic monitored
	3.2. Receive A/C calling in	FIXM (Coordination, EnRoute), CPDLC	KG	Communication with A/C established
	3.3. Identify A/C	FIXM (EnRoute), CPDLC	KG	A/C identified
4. ASSESS IF EXIT CONDITIONS ARE MET The system 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	4.1. Check sector boundaries	AIXM (Airspace Volume)	KG	Sector boundaries
	4.2. Check exit transfer conditions for the aircraft	Letters of Agreement, FIXM (EnRoute), 5.1	KG	Exit conditions
	4.3. Check that aircraft is flying towards the exit point	1.20, 5.1, 5.2	KG, Calculation layer, ML	• Aircraft is flying towards the exit point • Aircraft is not flying towards the exit point
	4.4. Check that aircraft will reach the exit point on the requested FL	1.11, 1.12, 1.13, 1.21, 5.1, 5.2	KG, Calculation layer, ML	• Aircraft will reach the exit point on the requested FL • Aircraft will not reach the exit point on the requested FL

being able to reach the exit conditions. In both cases, appropriate coordination or radar handover requests are assessed and planned.	4.5. Check that aircraft will reach the exit point at the expected time	1.18, 1.20, 5.1, 5.2	KG, Calculation layer, ML	• Aircraft will reach the exit point at the expected time • Aircraft will not reach the exit point at the expected time
5. CONFLICT MANAGEMENT	5.1. Check requested FL	1.1., 1.2., 3.5., FIXM (EnRoute),	KG	Requested FL
Identification of the conflict; Confirm suspicion of a conflict and gather additional details. Update the aircraft plan with the conflict solution.	5.2. Search aircraft pairs FDP (ADS-B) for conflicts	1.1, 1.3, 1.5, 1.7, 1.9, 2.2, 4.2, 4.4, 6.1, ML module	KG, Calculation layer, ML	• Conflicts detected in the FDP • Possibility of future conflict detected • No conflicts detected in the FDP
6. EXECUTE AIRCRAFT'S PLAN	6.1. Monitor A/C	FIXM (EnRoute), ML module	KG, ML	A/C under ATCO/ML surveillance
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.	6.2. Monitor coordination of any change in exit conditions	FIXM (CoordinationStatus)	KG	Coordination regarding change in exit conditions
	6.3. Monitor exit radar handover	FIXM (CoordinationStatus)	KG	Exit radar handover approved/ not approved
	6.4. Monitor forwarding new exit ETO	FIXM (CoordinationStatus)	KG	New exit ETO forwarded
	6.5. Monitor maintaining A/C separation	4.1., FIXM (EnRoute)	KG, Calculation layer, ML	A/C separation is maintained
	6.9. Monitor A/C changing FL	1.3., 1.4., 1.11., data from previous time-step, FIXM (EnRoute), ML module	KG, Calculation layer, ML module	A/C changes FL under ATCO/ML surveillance

	6.10. Monitor A/C changing heading	1.3., 1.4., 1.14., data from previous time-step, FIXM (EnRoute), ML module	KG, Calculation layer, ML module	A/C changes heading under ATCO/ML surveillance
7. TRANSFER AIRCRAFT System 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.	7.1. Check if exit conditions are met	5.2., 7.4, 7.5., FIXM (EnRoute), AIXM (CodeAirspacePointRoleBaseType), ML module	KG, ML	• Exit conditions are met • Exit conditions are not met
	7.2. Check if change of frequency is issued to A/C	FIXM (Coordination), CPDLC	KG	A/C receives new frequency
	7.3. Check if A/C switched frequency	FIXM (EnRoute), ML module	KG, ML	• A/C switched frequency • A/C did not switch frequency
	7.4. Change A/C colour on trajectory route display	FIXM (EnRoute), ML module	KG, ML	Colour change
8. RESPOND TO RECEIVED RADAR HANDOVER PROPOSALS Radar handover requires system'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.	8.1. Receive radar handover proposal	FIXM (Coordination)	KG	Radar handover proposal received
	8.2. Assess the proposal	FIXM (EnRoute), ML module	KG, ML, Calculation layer	Proposal assessed
	8.3. Verify the proposal	FIXM (EnRoute), ML module	KG, ML, Calculation layer	Proposal verified
	8.4. Monitor decision on the proposal	FIXM (EnRoute), ML module	KG, ML, Calculation layer	• Agree on the conditions • Disagree on the conditions
	8.5. Check if the agreed conditions on the conditions are conflict free	FIXM (Coordination)	KG, ML, Calculation layer	Conditions are conflict free
	8.6. Check if conditions are disagreed	FIXM (Coordination)	KG, ML, Calculation layer	Conditions not agreed upon
	8.7. Check if the plan is updated	FIXM (EnRoute)	KG	Updated plan

9. PROCESS SPECIAL AIRCRAFT REQUESTS System 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.	9.1. Receive request from the aircraft	CPDLC	KG	Aircraft request
	9.2. Check traffic situation	6.2, 6.3	KG, Calculation layer, ML	Awareness of the traffic situation
	9.3. Check aircraft type	FIXM, Aircraft performance data	KG	Aircraft type
	9.4. Check aircraft state	ML module, 2.1, 2.2, 7.1, 10.3	KG, Calculation layer, ML	Aircraft state
	9.5. Compute the traffic situation and workload if request is granted	ML module, 6.1, 6.2, 6.3	KG, Calculation layer, ML	Traffic situation and workload computed
	9.6. Compute the traffic situation and workload if request is denied	ML module, 6.1, 6.2, 6.3	KG, Calculation layer, ML	Traffic situation and workload computed
	9.7. Check if request is granted	CPDLC, FIXM	KG	Request granted
	9.8. Check if request is denied	CPDLC, FIXM	KG	Request denied
	9.9. Check if alternative is proposed	CDPLC, FIXM	KG	Alternative proposal
10. RESPOND TO AIRCRAFT REPORTS AND DISTRESS SIGNALS Responding to expected and unexpected (dis tress signals) reports from the aircraft.	10.1. Receive A/C report	FIXM (EnRoute), ML module, CPDLC	KG, ML	Report received
	10.2. Check if A/C report is acknowledged	FIXM (EnRoute), ML module, CPDLC	KG, ML	A/C report acknowledged
	10.7. Check if concerning sectors are informed	ML module	ML	Sectors informed
	10.8. Check if concerning units are informed	ML module	ML	Units informed
	10.9. Check if concerning airports are informed	ML module	ML	Airports informed
11. RESPOND TO ESTIMATED	11.1. Receive revision	CPDLC, FIXM (EnRoute)	KG	Revision received

TIME OVER (ETO) REVISION The response when an ETO change is received from the upstream sector;	11.2. Check if the plan is updated	AIXM (CodeServiceATFMType), FIXM (EnRoute)	KG	Updated plan
12. MAXIMISE QUALITY OF SERVICE	12.1. Monitor military airspace availability	AIXM (CodeMilitaryRoutePointBaseType), ML module	ML	Military airspace availability under surveillance
Look for QoS improvements from a/c position, from transit to exit. The best practice may already be a part of standard procedures.	12.2. Check if military airspace is available	ML module, 12.1	ML	• Military airspace is available for use • Military airspace is not available for use
	12.3. Check suggestion for shortened RBT	ML module	ML	• Suggestion accepted • Suggestion denied
	12.4. Check initiation for RBT renegotiation process	FIXM (TrajectoryRoutePair)	KG, ML	RBT renegotiation process initiated
13. WORKLOAD MONITORING	13.1. Monitor current workload level	ML module, 1.27, 2.1, 3.1, 4.1, 5.2, 5.3, 6.1, 9.2, 9.1, 10.1, 11.1, 12.1.	KG, ML	Current workload level under ML surveillance
Knowledge of current and future workload as a result of incoming traffic and plans made upon it. Self-analysis of workload by controllers.	13.2. Monitor future workload level	ML module, 13.1	ML	Future workload level under ML surveillance
	13.3. Plan co-ordinations to minimise future workload	ML module	ML	Plans for co-ordination
	13.4. Suggest co-ordinations that minimize future workload	ML module	KG, ML	• Suggestion accepted • Suggestion denied
	13.5. Inform supervisor about unmanageable workload	ML module	KG, ML	Supervisor informed

	13.6. Check if neighbouring sector is experiencing high workload	13.2, 13.3, FIXM (EnRoute), ML module	ML	• Neighbouring sector saturated • Neighbouring sector not saturated
	13.7. Suggest action to avoid saturated neighbouring sector	ML module	KG, ML	• Suggested action approved • Suggested action not approved
14. IDENTIFY MISSING INFORMATION	14.1. Identify aircraft with possible equipment degradation	CPDLC, ML module, Aircraft Performance Data	KG, ML	• A/C is experiencing equipment degradation • A/C does not have equipment degradation
	14.2. Check situation at destination airport	AIXM (AirportHeliportAvailability), ML module	KG, ML	• Destination airport is operable • Destination airport is inoperable
	14.3. Check situation at alternate airports	AIXM (AirportHeliportAvailability), ML module	KG, ML	• Alternate airport is operable • Alternate airport is inoperable
	14.4. Suggest deviation	FIXM (EnRoute), CPDLC, ML module	KG, ML	• Suggestion accepted • Suggestion refused
	14.5. Monitor adverse weather areas	ML module	ML	Adverse weather areas under surveillance
	14.6. Monitor restricted airspace	ML module	ML	Restricted airspace under surveillance
	14.7. Warn about severe weather	CPDLC, ML module	ML	Warning about severe weather
	14.8. Warn about restricted airspace deactivation	CPDLC, ML module	ML	Warning about restricted airspace deactivation
	14.9. Warn about restricted airspace activation	CPDLC, ML module	ML	Warning about restricted airspace activation
15. Monitor the status and performance of	15.1. Check status of CPDLC coverage	CPDLC	KG	Status of CPDLC coverage
	15.2. Check status of NAVAIDs	AIXM (Navaids)	KG	Status of NAVAIDS

ATC sub-systems	15.3. Monitor the performance of ATC CNS equipment	15.2, ML module, previous time-step, system state indication	KG, ML	Status of ATC CNS equipment
	15.4. Monitor the performance of ATC separation tools	System state indication, previous time-step, ML module	KG, ML	• ATC separation tools perform properly • ATC tools don't perform properly
	15.5. Issue an alert in case of performance degradation	15.1, 15.2, 15.3, 15.4, ML module	ML	ATC receives an alert about sub-system performance degradation

Table 1 Requirements for Knowledge Engineering of Selected ATCO Tasks