Case studies introduction: level of automation analysis and certification issues

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Abstract

This document presents a detailed description of the case studies being addressed by the HUCAN project, highlighting in particular the level of automation and the human-factor impact of the reference systems. In addition, the deliverable provides a preliminary analysis of the gaps and challenges regarding the assessment of the level of automation and the liability analysis, based on the specification of the case studies.

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HUCAN

HOLISTIC UNIFIED CERTIFICATION APPROACH FOR NOVEL SYSTEMS BASED ON ADVANCED AUTOMATION

HUCAN

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1 Introduction

This section introduces the document, by describing its purpose (section 1.1), its scope (section 1.2) and its structure (section 1.3).

1.1 Purpose of the Document

HUCAN project aims to develop an agile and holistic certification approach, suitable for the new generation of highly automated systems foreseen in future ATM scenarios, based on human-centred automation, and able to also consider the impact on the workforce skills and training requirements. The project adopts a case-study-based approach and focuses on novel operational concepts and technologies for on-demand capacity and dynamic airspace, including the integration of highly automated and AI-powered solutions and innovative services for U-Space.

Four case studies have been selected in order to study a holistic and unified approach to certification and to map the challenges that are associated with certification issues. The case studies cover different aspects of the capacity on demand concept, address different kinds of airspaces (i.e., middle airspace, TMA, U-space) and rely on different technologies. The case studies will be used to feed and validate the theoretical research, to design and test the certification method, and to produce and validate guidelines for certification.

This deliverable presents a description of the case studies being addressed by HUCAN, highlighting in particular the level of automation and the human factors impact of the reference ATM solutions. In addition, the deliverable provides a preliminary analysis of the gaps and challenges regarding the assessment of the level of automation and the liability analysis, based on the specification of the case studies.

1.2 Scope of the Document

The document represents deliverable D4.1 (*Case studies introduction: level of automation analysis and certification issues*) of HUCAN project. It presents a detailed description of the four case studies being addressed during the project, specifying:

- the purpose, the objectives and the automation role of each case study;
- the human factors impact of the reference ATM solutions;
- the level of automation of the reference ATM solutions;
- a preliminary liability analysis for each case study.

The deliverable feeds into the following next HUCAN tasks:

- Task 4.3 (*Development of the new approach to approval and certification*), which will develop the new certification approach in sufficient detail to enable application in the case studies;
- Task 4.4 (*Evaluation/validation of the new approach*), which will test the new certification approach on the case studies;
- Task 5.3 (*Guidelines and toolkit validation*), which will validate the guidelines and the toolkit of HUCAN by using the case studies.

1.3 Structure of the Document

The document is structured in the following chapters:

- Chapter 1 (Introduction) provides the introduction of the document.
- Chapter 2 (Detailed Specification of the Case Studies) reports the specification of each case study.
- Chapter 3 (Human Factors Change Analysis) describes the impact (i.e., changes) on human aspects of the case studies.
- Chapter 4 (Level of Automation Assessment) reports the assessment of the level-of-automation of the case studies.
- Chapter 5 (Liability Analysis) reports the preliminary analysis of the liability aspects of the case studies.
- Chapter 6 (Conclusion) provides the conclusion of the document and summarises the main certification aspects and issues identified during the analysis of the use cases.
- Chapter 7 (References) lists the references.
- Chapter 8 (List of Acronyms) provides the list of acronyms.
- Appendix A (Case Studies Forms) illustrates the summary forms of the case studies.

2 Detailed Specification of the Case Studies

This chapter reports the detailed specification of the case studies considered in the HUCAN project. Such specification is presented by describing the following features for each case study:

- the **purpose**, that is a short description of the case study and its scope with respect to ATM;
- the **objectives**, which represent the capabilities implemented in the case study;
- the **automation role and techniques**, which represent the detailed advanced-automation capabilities in the case study, highlighting the role of AI (if any) and the technical approach (e.g., algorithms, data, etc.) foreseen/planned/applied for the implementation.
- the **TRL** of the case study.

Section 2.1 presents a general overview of the case studies. The detailed specifications are reported in sections 2.2, 2.3, 2.4, and 2.5.

2.1 Overview

A set of four case studies has been selected to support the HUCAN project in ensuring a holistic and unified approach to certification. These case studies will be used:

- to map the possible challenges that are associated with certification issues;
- to feed and validate the HUCAN theoretical research;
- to test the proposed certification approach in HUCAN;
- to validate the HUCAN guidelines for certification.

The case studies cover different aspects of the capacity on demand concept, address different kinds of airspaces (i.e., middle airspace, TMA, U-space), and are based on different technologies and kinds of algorithms (both deterministic and non-deterministic AI-powered ones). Table 1 illustrates the HUCAN case studies and shows a summary of their purposes and objectives.

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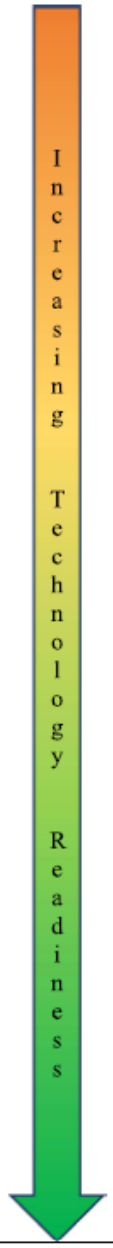
Table 1. HUCAN case studies.

Id.	Name	Purpose	Objectives
1	**Dynamic airspace sectoring**	Improvement of middle airspace utilisation obtained by means of dynamic optimisation of the airspace sector configuration	Dynamically define and apply the best allocation of elementary sectors for: • ATCOs workload optimisation • Capacity optimisation • Flow management optimisation
2	**AI-powered digital assistant in TMA**	Optimisation of the application of advanced continuous descent operations in TMA, by means of a DA for Spacing, Scheduling and Conflict Detection and Resolution (CDR)	Provide an AI-powered DA to support ATCOs to effectively manage inbound traffic and ensure continuous descent operations, with benefits for: • Safety in terms of ICAO longitudinal/lateral separations • Runway capacity maximisation • Fuel consumption minimisation • Environmental impact minimisation • Pilot and ATCO workload optimisation
3	**Dynamic Airspace Reconfiguration Service for U-space**	Dynamic U-Space volumes definition and information exchanges between ATM and U-Space	Dynamically support ATCOs in activating/deactivating U-Space volumes to UAS traffic for management of priority operations, emergencies, of manned aviation in U-Space, with benefits in: • Optimisation of U-Space as well as controlled airspace • Increase of safety levels • ATCO workload reduction.
4	**Dynamic allocation of traffic between ATCO and system**	Improvement of upper airspace utilisation by means of dynamic allocation of traffic between the ATCO and ARGOS	Dynamically support the ATCOs in managing the traffic in the sector, by means of issuing operational clearances to safely handle basic traffic situations and aid controllers in handling complex traffic situations. ARGOS has 3 modes of use. Two of them will be taken into account in HUCAN concerning respectively the autonomous management of the traffic by ARGOS in specific circumstances and the hybrid management of the traffic between the ATCO and the ARGOS system (dynamic allocation of traffic).

For the TRL of the case studies, its evaluation has to take into account the conventional TRL scale defined by NASA in 1995 but also the new attempts proposed in the literature to include AI. An alternative new wording of level descriptions has been proposed by Meystel et al in 2003 [10] to fit the TRL to different technology applications, including intelligent systems, as shown in Figure 1. Where appropriate, also this scale may be used as a reference for the TRL evaluation of highly automated and AI-powered systems.

Technology Readiness Level scale based on Meystel et al. (2003).



Level	Description	Diagnostic Questions
TRL 1	Basic Principles and Broad vision	Have you researched the system in principle? Do you have a vision for the system?
TRL 2	Conceptual design	Have you proposed engineering components which need to be part of the system? Do you have a conceptual design for the system?
TRL 3	Theoretical & experimental analysis. Proof of concept	Have you experimented with subcomponents of the system? Have you scrutinized innovative components?
TRL 4	Component validation in "laboratory" conditions	Have you integrated subcomponents of the AI system to check that they will work together? Have you considered issues such as interoperability, maintainability, scalability, security etc.?
TRL 5	Component validation in more realistic conditions	Have you developed a high-fidelity prototype of the system with reasonably realistic components? Have you verified the prototype works as desired?
TRL 6	Subsystem model or prototype demonstration	Have you demonstrated a prototype system in a relevant environment (e.g. lab test with realistic data or test in simulated environment)?
TRL 7	System prototype demonstration in operational environment	Do you have an operational system that can be demonstrated in its operational environment? Are there processes in place to support the software?
TRL 8	Actual system completed, tested and demonstrated	Do you have a system which is in its final form and meets its design specifications? Is it ready to work in its intended application?
TRL 9	Actual system proven through operational use	Has the software been used under operational conditions for an extended period? Has it been debugged? Does it reliably produce the required outputs?

Figure 1. TRL scale including Intelligent Systems proposed in [10].

Nevertheless, it is worth noting that in the last years the scientific community has been reviewing the TRL scale for a system dealing with AI. The key point is: what does readiness for an AI system mean? The literature converges on the point that the TRL approach is an important component of AI discourse because it illuminates **adoption as a process**, so that it is possible to uncover factors which belong to the AI World that are the enabling elements to deploy AI beyond isolated applications, or to maintain it in use long term [11]. Considering the new possible approach proposed in [11], TRL levels 2–4 are associated with *"selection of AI technology is distinguished"* where the stakeholders have been highly involved in the process to understand where AI can produce benefit.

The following sections provide the detailed specification of each case study.

2.2 Case Study 1: Dynamic Airspace Sectoring

This section describes case study 1, regarding automated support to decision for dynamic airspace sectoring.

2.2.1 Purpose

To enhance ATM and meet the future traffic demand and environmental requirements, the present ATM system is going to be modified by new services to be integrated in the future architecture considering the evolution of the present fragmented structure of the airspace and the entanglement of air routes. Such a change process is complicated due to the nature of ATM, which is a large-scale Socio-Technical System (STS), typically involving a complex interaction between humans, machines and the environment. In such systems, managing their evolution is a complex and difficult task since the social and technical implications of any proposed concept should be fully assessed before a choice is made whether or not to proceed with the related development. A quite common mismatch between the performance evaluations in simulated conditions and those achieved in real life is represented by the partial assessment of human aspects that can be performed throughout the new concept lifecycle from its lowest maturity level up to "ready to market".

The proposed case study defines an approach to support the design of new ATM solutions, including the evaluation of human behaviour. The approach adopts a combined computational paradigm, which involves Agent-Based Modelling and Simulation (ABMS) to specify and analyse the ATM models, and Agent-based Evolutionary Search (AES) to optimise the design of the new solutions. The purpose is to explore new configurations for the ATM system in advance, namely during the strategic (i.e., several days before the actual operations) or pre-tactical phases (i.e., up to several hours before the actual operations). Such optimisation is intended with respect to the estimated performance of the simulated ATM system and implies the minimisation or maximisation of some reference ATM performance metrics in the identified simulation scenario.

The proposed case study regards the design of sector collapsing/decollapsing configuration to optimise controller workloads. In detail, it delivers the automated and optimal tuning of the configuration of elementary sectors in the collapsed sectors in order to optimise controller workload, for both Executive Controllers (ECs) and Planner Controllers (PCs). Thus, **this case study aims at supporting the design of the sector collapsing/decollapsing configuration for a given planned traffic in a performance-based setting**.

2.2.2 Objectives

The goal of the case study is to find an optimal sector collapsing/decollapsing configuration in terms of allocation of elementary sectors in the collapsed sectors, i.e., allocation of PCs and ECs. The optimisation is dynamic and based on the planned traffic.

The compositions of collapsed sectors represent the parameters to be optimally tuned for the solution design (i.e., the decision variables for the optimisation).

The optimality has been intended in a performance-based setting, i.e., with respect to the minimisation of specific metrics related to the performance-oriented objectives. Such performance-oriented objectives are to limit the controller workload from the following points of view:

- the number of communications of EC to Flight Crews (FCs);
- the number of EC separation actions;
- the number of PC separation actions.

2.2.3 Automation Role and Techniques

In this case study, the role of advanced automation concerns the automated support to design of a new ATM concept in order to achieve the required performance levels. The new concept is related to the dynamic selection of sector collapsing/decollapsing configuration, based on the planned traffic.

The decision-support approach is:

- Simulation-based – The approach applies computational intelligence techniques which, combining ABMS and Evolutionary Computing, allow to carry out offline simulations for performing what-if analyses of ATM changes and for supporting the design of new solutions aimed at ATM system optimisation.
- Scenario-based – A scenario is intended as a description of the reference operating environment, including: a set of actors; a set of available actions; a set of processes; the relationships between the previous elements and their formalisation as a flow of information, representing the dynamics to allow the system to perform a mission or a service. The scenario integrates the change to be simulated and evaluated for the ATM system of interest.

The next subsections describe the overall workflow and its main activities, i.e., the agent-based modelling and the agent-based optimisation. Further details are available in [1], [2].

2.2.3.1 Support-to-Design Workflow

The workflow implemented for the support to design is shown in Figure 2 and is structured in the following way:

- The first activity is the specification of the model. Modelling specifications are structured using the FRAM (Functional Resonance Analysis Method) notation [3].
- The second activity prescribes the analysis of the FRAM model focusing on its design in a performance-based setting, which provides the statement of the optimisation problem.
- The third activity is in charge of the coding of the agent-based model associated with the FRAM-based specification. This is also called an evolutionary model since it is not fixed, but it is subjected to AES for the optimal tuning of design parameters. In parallel, the architecture for the agent-based simulation and the metrics evaluation module are set up. Also, the part of

evolutionary search is arranged and the optimisation problem is properly coded by implementing the AES engine.

- In the last activity, the AES engine exercises the evolutionary model for the iterative optimisation phase.

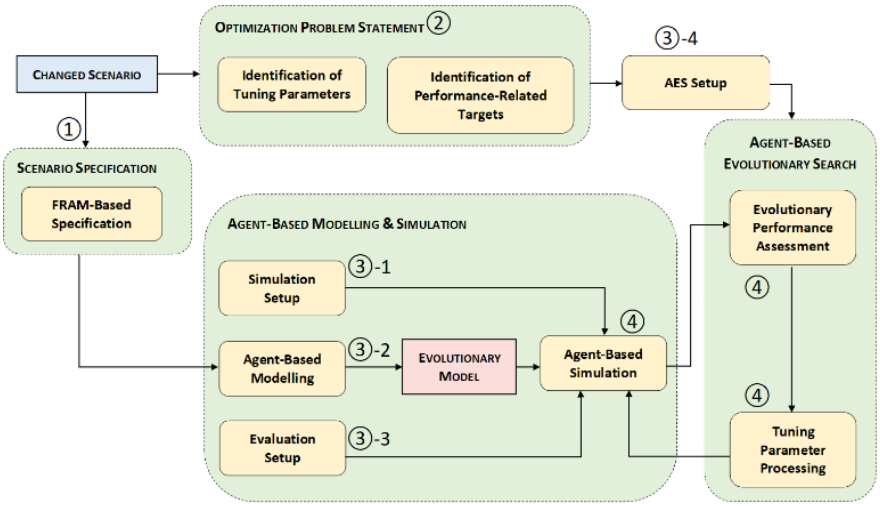


Figure 2. Proposed workflow for the support to design in case study 1.

2.2.3.2 Agent-based Modelling and Simulation

As mentioned above, the first part of the workflow relies on ABMS to provide the specification of the simulation models to be optimised within the support to decision of the case study. This case study assumes the involvement of a limited set of actors which are modelled as agents in our approach. Specifically, the scenarios involve: ATCOs, i.e., ECs and PCs across multiple sectors; Controller Working Positions (CWPs); aircraft; FCs. The architecture of the ABM simulator is shown in Figure 3. The implemented agents are the following:

- FC: this agent is responsible for flying an aircraft, and interacting with the ATCOs in order to obtain clearance to carry out several tasks.
- PC: this agent is the ATCO who is mainly responsible for the coordination of the traffic entering or exiting within the sector.
- EC: this agent is the ATCO who is responsible for the safe and expeditious flow of all lights operating within its sector. This agent monitors and separates flights that operate within its area of responsibility and, if necessary, it issues instructions to pilots for conflict resolution.
- Aircraft: this agent implements an aircraft. The reason why we have decided to implement the aircraft as agents is that different companies typically implement different flying strategies. Therefore, this level of abstraction allows us to better capture the intrinsic variability in the behaviour of different flights, and enhances the capability of the system to observe emergent behaviours.
- CWP: this agent implements the controller workstation where traffic can be monitored allowing for situational awareness. We have decided to implement a technical part of the system as an agent to reach the goal of allowing to perform what-if analyses of changes in the overall organisation of the ATM system.

For the modelling of the agents, the proposed approach exploits the FRAM notation to specify a model for the sociality of agents, i.e., the information that each agent needs to exchange with the others in order to perform its assigned functions. In detail, our approach customises the standard FRAM notation to adapt it as a "fastener" between the views of ATM experts (e.g., a specification by means of hierarchical task analysis) and agent-based modelling experts. With reference to Figure 4, each FRAM component (i.e., the hexagon) represents an action of an agent. Each agent is specified as a course of FRAM actions, that is a structured sequence of agent's actions, whose execution impacts on the generic performance metrics of the agent itself. The flow interactions among actions are expressed by means of FRAM interfaces as appropriate. This ensures the coexistence of technical and social characteristics in the specification.

Regarding the modelling of human agents, we have focused on modelling the human behaviour of the ATCO agents of the scenarios, specifically in their two roles of EC and PC. Conversely, FCs' behaviours have been modelled with a higher level of abstraction, using a characterisation of the interactions between the FC and the controllers as specified by the standard procedures of the airline to which the FC belongs. Following a scenario-based approach, it has been possible to break down the structure of the ATCOs' tasks relative to the case study. Then, a Hierarchical Task Analysis (HTA) has provided an operational description of the selected scenario and the identification of tools, external conditions, triggers and outputs per each task, as well as the identification of relevant human behaviour variables and attributes.

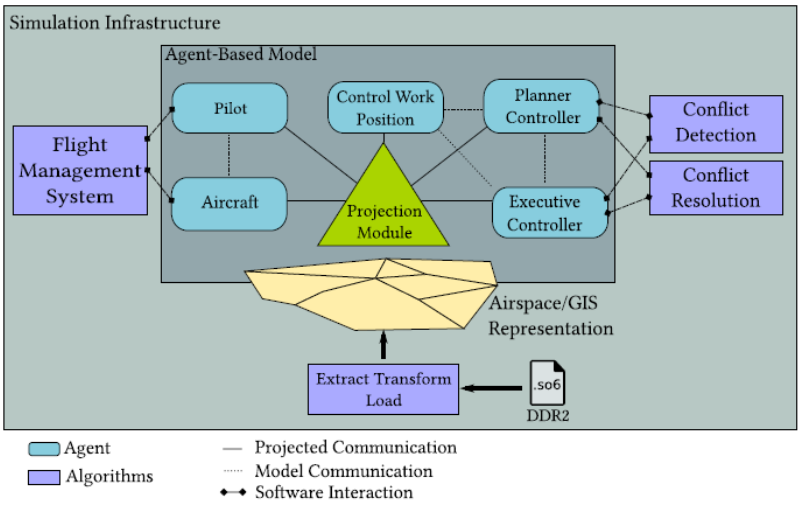


Figure 3. Architecture of ABM simulation system in case study 1.

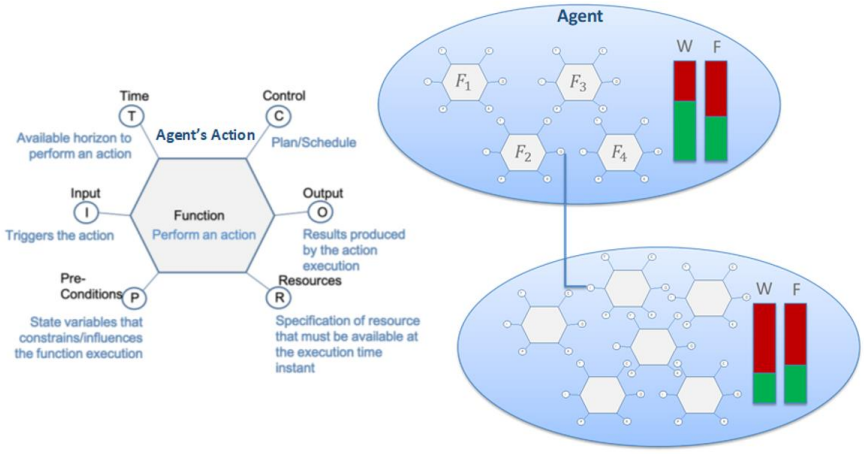


Figure 4. Customisation of FRAM components for the case study 1.

2.2.3.3 Agent-based Optimisation

The second part of the workflow involves the optimisation of the agent-based simulation models of the case study to identify the optimal configuration (input) parameters related to the allocation of ECs and PCs. In detail, the approach employs AES, being based on Evolutionary Algorithms (EAs), which are inspired by concepts from nature (e.g., evolution and natural selection) and provide effective heuristics for computationally intensive problems. They maintain a population of individuals (potential solutions), which compete for survival. New 'offspring' (new potential solutions) are created by recombining and mutating individuals selected from the population.

The exploration of the overall search space is driven by multiple objective functions, which are related to the reference performance metrics and may also include variables associated to human behaviour and controller workload. These functions address a multi-objective optimisation problem whose solutions identify the best-suited configurations of the input parameters. The multiple objectives must be jointly optimised at the same time, so that the fitness function used to evaluate the goodness of the individuals is directly derived from these objectives. Thus, the requirements for the optimisation approach are the following:

- There are multiple input variables to optimise and there are multiple output metrics to assess the goodness of a configuration. Thus, Multi-Objective EAs (MOEAs) is a proper choice for the design of the optimisation framework.
- Optimisation is simulation-based and the optimisation architecture must consider non-minimal execution times. This requires a parallel/distributed and simulation-based optimisation architecture.

In detail, our evolutionary computing solution is based on a parallel/distributed variant of NSGA-II (Non-dominated Sorting Genetic Algorithm II) algorithm. NSGA-II is a popular and widely used MOEA, which exhibits several properties that are fundamental to meet the optimisation requirements which we have set. The customisation of NSGA-II has led to a parallel/distributed simulation-based architecture, which aims at a resolution of the optimisation problem in a reduced amount of time. This architecture is based on the Master-Slave paradigm and is shown in Figure 5. The building blocks are the following:

- The Orchestrator: it is responsible for splitting the current population into different subsets of individuals, distributing the sets to the different available computing nodes, and controlling them along the computation.
- Compute nodes: they evaluate (through stochastic simulations) the goodness of an individual of the population. These compute nodes represent performance-critical elements. Indeed, for each individual of the population, the orchestrator schedules for execution multiple runs (the number is parameterisable) of the simulation model (with different random seeds).
- Compute metrics: they are activated after a batch of simulation is completed, and compute the average values for the metrics of interest. The final metrics are here computed from the logs of the ABM simulation and are associated with the individual.
- Selection and evolution: this block applies the evolutionary strategy to evolve the current population towards the optimal solution.

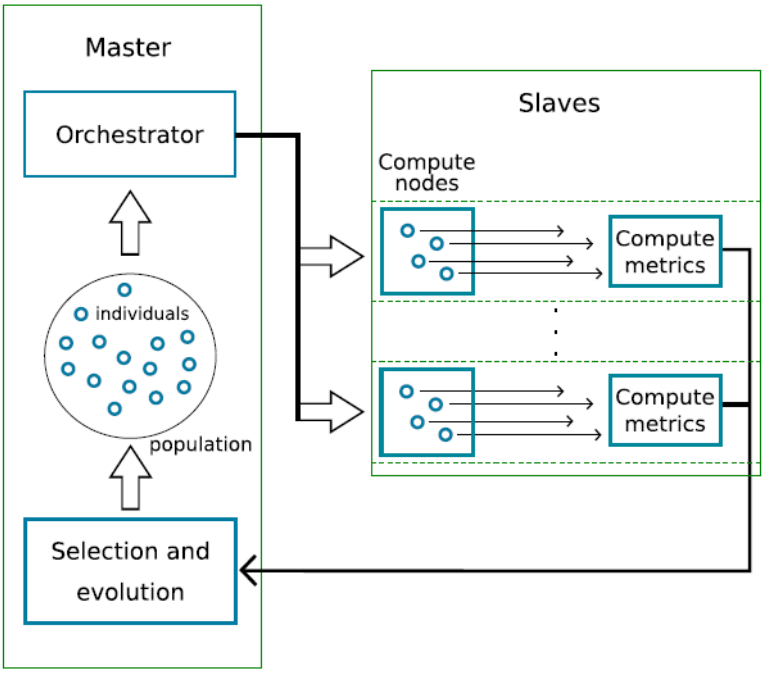


Figure 5. Optimisation architecture in case study 1.

The reference performance metrics for the optimisation of the agent-based model about airspace sectoring are:

- The total number of EC to communications – It is the sum of all the numbers of EC to FC communications in the simulated sectors.
- The standard deviation of EC to FC communication – It is the standard deviation of the distribution of the numbers of EC to FC communications in the simulated sectors.
- The total number of EC separation actions – It is the sum of all the numbers of EC separation actions in the simulated sectors.
- The standard deviation of EC separation actions – It is the standard deviation of the distribution of the numbers of EC separation actions in the simulated sectors.

- The total number of PC separation actions – It is the sum of all the numbers of PC separation actions in the simulated sectors.
- The standard deviation of PC separation actions – It is the standard deviation of the distribution of the numbers of PC separation actions in the simulated sectors.

The optimisation objectives of the AES are to find an airspace configuration (i.e., a collapsed sector allocation to ECs/PCs) to minimise all the previous metrics. The choice to optimise both the total workload metrics and their standard deviation is significant in order to find the optimal compromise with respect to the possible workload "dimensions". Indeed, on the one hand, the minimisation of the total performance metrics penalises the choice of an excessive decollapsing of sectors, i.e., the introduction of a high number of ECs and PCs. On the other hand, the minimisation of the standard deviations is useful as it aims at rewarding the configurations with a uniform workload for the distributions of ECs and PCs, which will reasonably prevent trajectory-related metrics from negative impacts.

In addition, a safety constraint is imposed about a maximum threshold for the hourly mean of STCA (Short Term Conflict Alert) conflicts in each collapsed sector. Such a constraint is useful to establish the "border line" between the safe state space and the degraded state space in the search space of solutions. Given that the ABMS engine is already set up with de-conflicting tools (which ensure conflict resolutions and mid-air collision avoidance, as shown in Figure 3), it is reasonable to use STCA conflicts as a safety indicator of the traffic complexity. Indeed, if a collapsed sector is subjected to an excessively complex traffic, a degradation will occur in human performance, which may be tracked by measuring STCA conflicts. If such conflicts exceed a critical threshold, the sector is too "wide" for the planned traffic: the current solution is degraded and the AES algorithm will likely decollapse the sector in the next solutions.

2.2.4 **TRL**

The case study leverages on **EVOAtm** (EVOlutionary ATM) project [8]. This was a SESAR ER project, funded by the call **H2020-SESAR-2016-2**, call topic **SESAR-ER3-06-2016 - ATM Operations, Architecture, Performance and Validation**.

Being an exploratory research project and an application-oriented research, the achieved results complied with a **TRL 2** (Technology concept and/or application formulated) [9].

2.3 Case Study 2: AI-Powered Digital Assistant in TMA

2.3.1 **Purpose**

The ATCO's task of maintaining safe separation between aircraft is going to become more demanding as the day-by-day higher levels of traffic bring an increase in potential conflicts. The complexity of the traffic situation increases every day, not only because of the increasing traffic but also because the diversity of technology, ground-based and airborne, adds new issues to be taken into account by ATM services. Nowadays, in view of the growing traffic volume, appropriate aircraft sequencing in the arrival sector is needed to maintain safety levels and improve the performance of the runway system and flight times.

This case study presents a digital assistant supporting the ATCO in aircraft sequencing by providing suggestions for next waypoints, speed adjustments and altitude holdings. On the one hand, the suggested paths are such to preserve safety by ensuring the prescribed minimum separation, while also promoting environmental benefits through continuous descent operations (CDO). On the other hand, the suggestions aim to reduce landing times, improving the runway throughput. The proposed case study exploits multipath planning, for which a global optimisation technique is used in conjunction with the dynamic time warping distance metric and a reinforcement learning approach to resolve conflicts through speed modulation and/or altitude holding. The performance of the assistant is assessed by means of a multi-agent simulator tailoring its reasoning on the procedures of Olbia airport (Italy). The DA provides AI algorithms to support the controller in decision making when applying final approach procedures (e.g., Point Merge System trombone routes). Considering the Trombone procedure, aircraft join the final approach via a fixed path. Sequencing is achieved through a single direct-to instruction issued to each aircraft along the legs, as soon as the required spacing with the preceding aircraft is obtained. When traffic permits, aircraft are cleared to the point without using the legs. The tactical instruction is provided by the controller relying on their experience. The proof of concept aims to support controllers in providing such tactical instructions. Deep RL techniques are applied to learn how to map situations to “direct to” instructions and to understand which are the most rewarding ones. The reward signal is related to some key performance indicators, such as safety, capacity and environment. Traffic data have been made available by ENAV (the Italian Air Service Provider) for the appropriate training and considers terminal areas with high complexity traffic. The approach is showing promising results. Some challenges are triggered by RL. In particular, the approach is expected to:

- avoid negative “side effects” when an AI agent is pursuing its goals;
- avoid “reward hacking”, i.e., reward maximisation without reaching the objective;
- ensure robustness to distributional shift, i.e., show the capability to generalise to “unseen” scenarios.

The proof of concept under study has been developed by CIRA in a National Project (NUVASC 2021-2023). The DA is referred to with the acronym ACOP (Arrival digital assistant with Conflict Prevention) [4].

2.3.2 Objectives

The objective of the DA under study is to assist ATCOs in the effective operational management of traffic during the arrival phase from the top of descent (TOD) up to the final approach fix (FAF) while following the trombone procedures. It is evident that the proper organisation of queue sequencing at an earlier time horizon can result in considerable advantages in relation to reducing the Arrival time, Conflicts in TMA, and maintaining CDO-like adherence for reducing CO2 emissions.

2.3.3 Automation Role and Techniques

DA provides two types of suggestions joining both sequencing and scheduling and conflict management functionalities issuing “Direct To” and “Conflict Resolutions Commands”.

The figure below reports the functional architecture of the ACOP. The ACOP is structured in layers acting on different tasks in the **sequencing and scheduling layer (SSL)** and the **conflict management layer (CML)**. The first layer provides a solution to the ASSP, while the second layer implements the CDR

functionality. This division is useful because the time horizons of the two problems are very different, and the two functionalities are decoupled. Even though the SSL guarantees separation at the FAF and spreads aircraft trajectories as much as possible, some LOSs could still occur if a dedicated CDR capability is not included. Consequently, the conflict management layer is needed to comply with the required safety levels.

The ACOP receives as inputs the aircraft three-dimensional positions, horizontal velocities and categories.

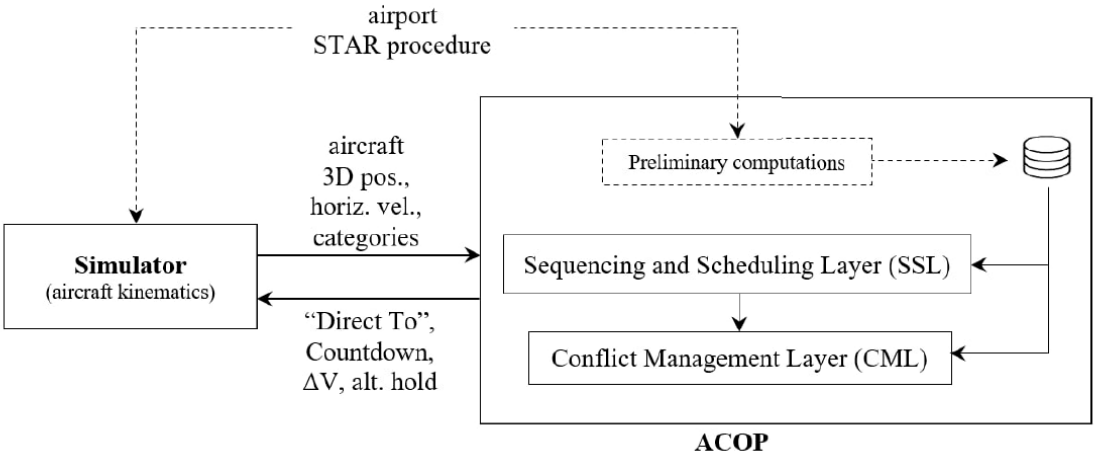


Figure 6. ACOP functional architecture [4].

The SSL is triggered when a new aircraft arrives at an initial fix, as no information is available on the upstream traffic. Therefore, the same aircraft can be rescheduled more than once because it is involved in multiple optimisation sessions. The SSL adopts an optimisation algorithm composed of two in-series optimisations. They are required to minimise the times of arrival and to reduce the scenario complexity.

The SSL layer is implemented by means of:

1. a genetic algorithm whose cost function to be minimised is assumed to be the sum of the planned estimated times of arrival (ETA) of each aircraft;
2. a dynamic time warping (DTW) algorithm to select among the multiple solutions provided by the optimisation step. The scenario with the largest average DTW value is selected and proposed to the controller.

The **Conflict Management Layer** (CML) is composed of two different sub-functions:

- Conflict detection between all possible pairs of aircraft and;
- Conflict resolution to separate aircraft by reducing speed and/or holding altitude.

The conflict resolution function is implemented by means of Reinforcement Learning. In the CR, only two actions are supposed to be available: speed reduction and altitude holding. When the CPA is defined (i.e., a conflict is detected), three different cases can be distinguished:

1. An immediate speed reduction within the admissible speed range of [v_min;v_max] kts is applied to resolve the conflict.
2. If there is no feasible speed reduction value within the admissible range, the altitude of the highest aircraft is held until the CPA is reached. More specifically, the holding altitude is set at 1000 feet above the expected conflict altitude. Of course, this manoeuvre breaks the CDO-like profile if the altitude holding lasts longer than 20 s [12]; however, it is necessary to avoid conflicts and maintain safety.
3. If there is no speed reduction value capable of solving the detected conflict and the aircraft are only vertically separated (the aircraft are "one above the other"), we combine a predefined deceleration with an altitude holding of the highest aircraft.

In the first case, the applied speed reduction is the minimum possible to avoid the horizontal infringement and is determined using a reinforcement learning (RL) approach. When a potential conflict is detected, the trained AI model is called and returns an appropriate speed reduction for one aircraft only. If the RL solution results in a velocity value outside the allowable range, this means that speed reduction is not a feasible way to prevent the conflict, and another approach must be considered.

RL technique requires the following steps:

1. to model the environment where the agent acts (learning environment);
2. to model the agents in terms of their space of actions and the observation space;
3. to model the reward function;
4. to implement the algorithm.

The RL agent training process for conflict resolution is briefly explained in the following. First of all, conflict scenarios are generated for aircraft pairs and presented to the agent using a custom simulated environment, called learning environment. The agent, guided by the RL algorithm, learns to solve these conflicts by applying a speed reduction also given the environmental uncertainty. The aircraft "to be controlled" is chosen considering the vehicle that is at a greater time distance to the expected CPA. For such a manoeuvre, the agent receives a reward as performance feedback, and the value of the reward depends on the quality of the manoeuvres. The learning goal is to maximise the reward, and the agent is considered trained when consistently achieving high rewards for solving "never seen" conflict scenarios.

2.3.4 TRL

The case study leverages on a proof of concept developed in a National Project, funded by the Ministry of Education 2020-2026. The Project NUVASC has been structured in different phases and has covered different use cases focusing on AI in aviation. NUVASC Use Case 1 developed in 2022-2023 is the Digital Assistant – referred to as ACOP – and considered in HUCAN. The requirements have been collected by interviewing ENAV operational staff and a preliminary validation in a laboratory has been conducted and submitted to ENAV and results have been shared. The research has been published in a journal and referenced in [4].

The TRL evaluation for this case study considers the scale proposed by Meystel et al in 2003 [10] to fit the AI-powered functions, without the support of additional validation activities. In detail, based on Figure 1, the TRL assigned to the case study is 3, corresponding to "Analytical and experimental critical

function and/or characteristic proof-of-concept". In fact, at this step in the maturation process, active research and development (R&D) has been initiated, considering both analytical studies to set the technology into an appropriate context and laboratory based studies to physically validate that the analytical analysis have been correct.

In addition, considering the definition in [11], the TRL assigned is again 3 instead of 4, since the function has been identified with stakeholders, the technology has been selected and proved, but just the single function in a rough simulated environment.

2.4 Case Study 3: Dynamic Airspace Reconfiguration Service for U-Space

This section describes the case study 3, regarding an advanced support to decision for dynamic airspace reconfiguration inside U-space airspace[3].

2.4.1 Purpose

The case study described relates to one of the Essential Operating Changes within the ATM Master Plan, namely U-space services, in particular, the Dynamic Airspace Reconfiguration (DAR) service. The DAR service is defined in EU REG 665 as: "The temporary modification of the U-space airspace in order to accommodate short-term changes in manned traffic demand, by adjusting the geographical limits of that U-space airspace."

The service, as delineated in EU Regulation 664, holds significant importance within the broader safety framework governing operations in U-space airspace. It pertains to **U-space airspace situated within controlled airspace**, allowing manned aircraft to fly clear of the U-space airspace whilst ensuring the containment of the U-space traffic. Dynamic reconfiguration, orchestrated by ATC units, responds to fluctuating patterns of manned traffic, necessitating short-term adjustments in U-space airspace. Initially, efforts should be made to minimise the frequency of dynamic airspace reconfiguration instances. Furthermore, strategic measures, such as optimising the design of U-space airspace as well as the management of Demand and Capacity Balance (of U-space users), can curtail the need for extensive adjustments. Enhanced airspace design facilitates ATC units in effectively segregating manned and unmanned aircraft within U-space airspace. Operationally, ATC units notify U-space service providers (USSPs) about segments of U-space airspace ineligible for UAS flight authorisation, activation, and utilisation based on U-space airspace design. During dynamic deactivation of these segments due to tactical, short-term changes in manned traffic demand, USSPs are advised not to grant flight authorisation/activation. Instead, they should prompt UAS operators within deactivated segments to either vacate or land. Time margins for these operations are determined on a case-by-case basis, considering various factors like ATC route proximity, typical aircraft performance, airspace constraints, or unforeseen circumstances.

[3] According to Regulation (EU) 2021/664: U-space airspace means a UAS (unmanned aerial systems) geographical zone designated by Member States, where UAS operations are only allowed to take place with the support of U-space services. U-space service means a service relying on digital services and automation of functions designed to support safe, secure and efficient access to U-space airspace for a large number of UAS.

In general, as described in the AMC/GM to Implementing Regulation (EU) 2021/664 - Issue 1, the process consists of distinct steps, which can be summarised as follows:

1. **Initiation of Dynamic Airspace Reconfiguration Procedure:** The ATC unit decides to issue clearance for a manned aircraft to enter the U-space airspace, prompting the initiation of the dynamic airspace reconfiguration procedure.
2. **Notification to UAS Operators:** The ATC unit alerts UAS operators/pilots, through their respective USSPs, about the upcoming deactivation of either the entire U-space airspace or relevant portions.
3. **Publication of Temporary U-Space Airspace Restriction**: The ATC unit publishes a temporary U-space airspace restriction for UAS as part of the Common Information System (CIS) for that airspace.
4. **Adherence to Restriction by USSPs:** USSPs operating within the airspace adhere to the temporary restriction, disseminating the information to all connected UAS operators/pilots.
5. **Verification and Amendment of Flight Authorisations**: USSPs cross-verify authorised UAS flights against the new restriction and make necessary cancellations or amendments to flight authorisations.
6. **Notification to UAS Operators/pilots**: UAS operators receive notifications through the UAS flight authorisation service, informing them to either halt their flights or comply with amended authorisations.
7. **Clearance of Restricted U-Space Airspace:** USSPs notify the ATC unit once the restricted portion of the U-space airspace is clear of UAS traffic.
8. **Clearance for Manned Aircraft Entry:** The ATC unit permits manned aircraft to enter the U-space airspace once segregation from UAS traffic is confirmed.
9. **Conclusion of Dynamic Airspace Reconfiguration Procedure**: Upon completion of the manned flight through the U-space airspace, the ATC unit concludes the dynamic airspace reconfiguration procedure by lifting the restriction.
10. **Resumption of UAS Flight Authorisations**: USSPs are then allowed to resume UAS flight authorisations or issue new ones to UAS operators/pilots as necessary.

In order to be able to perform such a process, the use of certain services, both U-space and ATM, is required. First consideration to be made is related to **the four mandatory U-space Services:**

a. **UAS Flight Authorisation Service:** This service evaluates the submitted U-plan and authorises the UAS operations that do not spatially and temporally intersect with any other notified UAS flight authorisation within the same portion of U-space airspace or other airspace restrictions.
b. **Geo-awareness Service:** This service offers UAS Operators information on current airspace restrictions and specific geographical zones relevant to UAS activities.
c. **Network identification Service:** This service supplies UAS Operator identities, UAS location, and flight paths during both nominal operations and contingency scenarios, with the additional duty of sharing relevant data with other U-space airspace users.
d. **Traffic Information Service (TIS):** This service provides traffic information and warnings to the Remote Pilot or UAS operator about other flights in close proximity to their UAS flight/s, including manned and unmanned traffic.

In addition to these four services, depending on the characteristics of the U-space airspace or considering the requests of the National Authority, two other U-space services, normally called "optional services," may also be added:

e. **Weather Information Service:** This service collects and presents relevant weather information for the UAS operation. This includes hyperlocal weather information when available/required. The service may be used for airworthiness decisions – for example does the visibility exceed mandated minima.
f. **Conformance Monitoring Service:** The monitoring service provides conformance monitoring of UAS operations to their intended trajectories as defined in their U-plans.

In addition to the basic services described, which include the four mandatory ones as per EU REG 664, and the two optional ones, we have other U-space type services that we consider as "Advanced." These services turn out to be useful to implement, especially in complex U-space Volumes, such as those in controlled airspace, thus also subject to DAR. These services are:

g. **Strategic Deconfliction:** Within a U-space volume, the USSPs offer a strategic deconfliction service to UAS Operators to deconflict U-plans (i.e., ensure there is no “intersection” between pairs of trajectories) pre-flight. With this service implemented, regardless of the (re)configuration of the airspace, UAS operations will be strategically deconflicted from other UAS operations within the U-space volumes.
h. **Emergency Management Service:** This service has two aspects: 1. assistance to a drone pilot experiencing an emergency with their drone, and 2. communication of emergency information to those who may be interested.

In a complex process such as DAR, especially important is the **exchange of information between the ATM and UTM parts**. In fact, ATC needs to have a lot of information coming from the U-space part. For this reason, it is necessary to mention the main information exchange services:

i. **U-plan Information Exchange Service:** A safety-critical, access-controlled service that manages live U-plans submitted via the U-plan preparation service and checks them against other services. The service manages authorisation workflows with relevant authorities, and dynamically takes airspace changes into account. This service enables ATC to have visibility of U-plans (when necessary).
j. **UAS Zone Information Exchange Service**: This service provides a means of exchanging across the ATM-U-space collaborative interface the fact that all the geofences that have been previously designed and implemented within controlled airspace are collectively activated or deactivated at a given time.
k. **Tracking Information Exchange Service:** The Tracking service transfers positional (position and altitude) data between ATM and U-space actors.
l. **Traffic Conformance Monitoring Information Exchange Service:** The Non-Conformance Monitoring will be calculated with input from the U-Plan and the Traffic Information Exchange Service. If a deviation is detected a Non-Conformance alert can be sent. The USSP can inform the ANSP (via the CISP) about the non-conformance of a UAS immediately. On the same basis the ANSP can inform the USSP (via the CISP) if a manned aircraft is deviating from its accepted flight plan or clearance and infringing on a U-space volume.

m. **Tactical Operational Message Data Exchange Service:** The Tactical Operational Message Information Exchange Service transfers operational messages, such as instructions from ATC or a USSP (e.g., "Land now!"), and the corresponding acknowledgements (via the CISP). The data exchanged can include tactical alerts.

The implementation of a full DAR service in the future is set to revolutionise the European ATM system. This advance facilitates the seamless integration of UAS traffic through dynamic airspace management, with several benefits. These include wider and more equitable access to airspace for various users, increased operational capacity for both manned and unmanned flights, simplified operations, and improved human performance through **innovative support tools**. Importantly, these benefits are achieved without compromising safety or environmental concerns. DAR service has been the subject of major SESAR projects in recent years, especially the PJ34-W3 AURA industrial research project, completed in 2023, and the ENSURE fast track project, which is still ongoing.

One of the solutions in the AURA project was to define the ATM/U-space interface by identifying the necessary data exchanges between ATM and U-space systems and defining the shared information. This process led to the creation of a set of core services that enabled information exchange through SWIM (System Wide Information Management) as middleware for the interface of ATM-U-space systems. These defined information exchange services created the initial common ATM-U-space interface. By defining the common interface between U-space and ATM through an initial set of core services and considering the relevant information for exchange, interoperability between the two systems was ensured. This approach avoided airspace fragmentation and facilitated safe drone operations in both controlled and uncontrolled airspace.

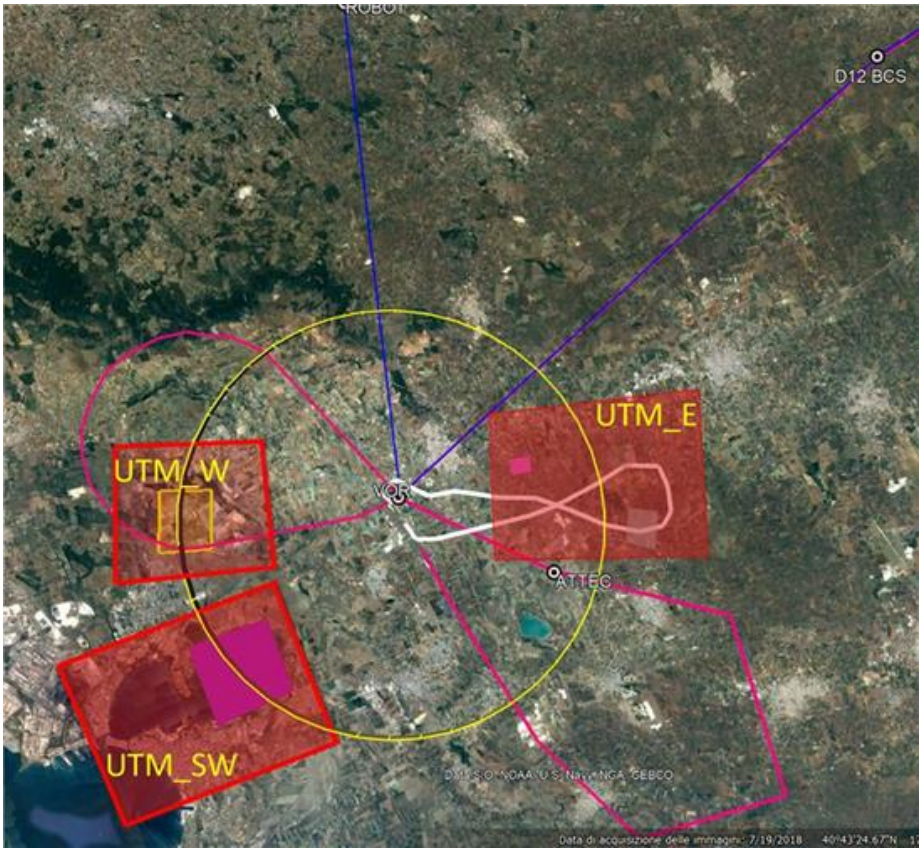


Figure 7. DAR simulation carried out in the AURA project.

The follow-up project ENSURE aims to refine and complete the definition of a common interface and services for U-space and ATM. The project is developing a standardised data model, architecture, and operational methodology. Additionally, it is creating a dynamic airspace configuration service to assist ATC actors responsible for airspace reconfigurations in maintaining traffic segregation and avoiding proximity between manned and unmanned aircraft within the designated U-space. This service is continually defining/evolving and there is a need for continuous synergy between the projects, both of which are ongoing. For this Case Study, it is therefore important to take the innovations of the ENSURE project as a reference, to analyse and hypothesise where modern AI technologies can support the DAR process.

The functionality detailed in ENSURE Operational Service and Environment Definition (OSED) for the DAR service relies on utilising the ATM-U-space interface for operation and transmission of essential information among various actors and systems. Introducing the DAR service entails establishing a fresh role in ATC airspace management, specifically the **Dynamic Airspace Reconfiguration Manager**. The protocols and framework governing the DAR process will prioritise transparency and equity in managing all users of shared airspace, irrespective of their ATC service status. This novel role will be complemented by automated support tools, aimed at alleviating the workload for both the designated managers and other human participants, such as ATCOs. The main Roles and Responsibilities involved in the DAR service are described below.

Table 2. Case study 3 – roles and responsibilities.

Roles	Responsibilities
UAS Pilot	The UAS Pilot is responsible for flight controls or monitoring the operation. The UAS pilot will have the option of requesting an extension of its operation area through a reverse DAR request. The UAS Pilot shall have the opportunity to request an extension of the area in order to carry out their mission.
Dynamic Airspace Reconfiguration Manager (DARM)	This is an ATC role responsible for providing the DAR service, implementing modifications to the geographical extent of U-space volumes in response to ATC and USSP DAR requests. The DARM should monitor AUSA (ATM-U-space Shared Airspace) and have full situational awareness of both manned operations receiving an ATC service and UAS operations taking place. They will follow procedures to assess, decide, and implement the DAR. This may include "what-if" scenario planning through coordination with the ATCOs and USSPs to ensure viability of the proposed volume changes. The DARM shall also ensure safety after each (de)activation by receiving compliance confirmation messages from the relevant service providers.
U-space Service Provider (USSP)	The USSP is a stakeholder who provides at least one of the U-space services (but depending on the interpretation of the regulation, a certified USSP may need to provide all four mandatory services at the same time). The entity that provides U-space service access to UAS operators, to pilots and/or to drones, to other operators visiting non-controlled airspace. Depending on the architecture deployment options and the services, different U-space service providers could provide multiple services to multiple UAS Operators. The USSP is responsible for translating U-plans into requests to reconfigure the airspace and transmitting those to the DARM (via the CISP). During the DAR (de)activation, or any other new airspace restrictions, the USSP must guarantee its communication to the interested UAS operators, or to the ATM, depending on the situation. The USSP must also determine whether the UAS Operators have complied with the DAR and send compliance confirmation to the DARM.

Common Information Service Provider (CISP)	The CISP is concerned with the provision of the necessary information to ensure the ecosystem functions well. Its objective is to ensure that the information comes from trusted sources and that it is of sufficient quality, integrity, and accuracy as well as security so that the USSPs and other users such as ANSPs can use this information and trust its reliability when providing their services. The CISP needs to provide the adequate situational awareness by promulgating the corresponding information stored coming from both ATM and U-space sides. Regarding the application within the DAR concept, this regards continuously transmitting updates of airspace restrictions whenever they are originated or approved from ATM. Furthermore, the CISP provides a centralised gateway for all USSPs to interact with the ANSP, proposing itself as coordinator of data exchanges between the stakeholders in both strategic and tactical phases. Moreover, as a second step from the storage of information, CISP is responsible for propagating the correspondent update on airspace restrictions whenever a DAR or reverse DAR is applied. This information is communicated both to ATM and U-space actors.
Aerodrome ATS (part of ANSP)	The Aerodrome ATS is a provider of air traffic services to airspace users. It can be an ATS Aerodrome or an ATS Approach service provider. It has the role of developing, jointly with the CAA, the volumes within the Za airspace (high density ATC-controlled airspace), in order to create volumes that allow efficient management of manned traffic in receipt of an ATC service and UAS traffic, while minimising the potential disruption to the normal circulation of aircraft within a CTR. It will be important to develop an HMI suited to the situation: physical stress, attention and skills must be assessed with live validations and an Interface Design process must be completed.
Air Traffic Controller (ATCO)	ATCOs must not be exposed to situations where the workload exceeds the maximum admissible, especially when considering DAR interactions. ATCOs have situational awareness, when necessary, to make informed decisions. In addition to their traditional functions, ATCOs also coordinate with the DARM to provide the DARM with an assessment of what is viable. In this context, they need to be aware of the (de)activation of U-space volumes and any changes to the airspace that are being implemented whilst not receiving unnecessary information which relates to operations or airspace outside his/her responsibility. The ATCOs must also notify the DARM once a volume of airspace that has been reconfigured to U-space is clear of manned traffic (i.e., confirmation of compliance with the DAR). The ATCO may take on the role of the DARM in certain situations where the traffic volume and complexity is particularly low.

The DAR service, therefore, involves different Actors with different roles and responsibilities. The operational flow is the focus of many studies and debates as described above; however, it is evident how the use of advanced capabilities and innovative technologies, such as those from AI, **can support DARM in the reconfiguration process**.

2.4.2 Objectives

The successful implementation of the Dynamic Airspace Reconfiguration (DAR) process, along with the development of advanced technologies, relies heavily on efficient, reliable, and secure communication

and information exchange between ATM and U-space actors across strategic, pre-tactical, and tactical phases. This exchange of information is crucial for optimising airspace utilisation by various stakeholders, both manned and unmanned, and is contingent upon the digitisation of systems to streamline communication mechanisms through collaborative interfaces.

Therefore, the primary objectives of this case study include **providing highly automated tools capable of partially replacing the role of the Dynamic Airspace Reconfiguration Manager (DARM),** while ensuring human oversight at the supervisory level and as the final decision-maker. The key objectives can be outlined as follows:

1. **Operational Efficiency:** Automation can streamline the dynamic airspace reconfiguration process, enabling the DARM Manager to handle reconfiguration requests swiftly and accurately.

2. **Reduction of Human Errors:** Automation mitigates the risk of human errors in reconfiguration decisions, ensuring greater consistency and precision in decision-making.

3. **Faster Response to Changes:** Automated technologies empower the DARM Manager to respond promptly to fluctuations in air traffic and reconfiguration demands, enhancing operational flexibility.

4. **Adaptability to Traffic Volumes**: Automation enables dynamic adjustment to evolving traffic volumes, automatically fine-tuning airspace configurations to meet specific needs in real-time.

5. **Workload Reduction:** By automating repetitive tasks, the DARM Manager's workload is lightened, allowing for increased focus on complex and strategic responsibilities.

2.4.3 Automation Role and Techniques

Dynamic Airspace Reconfiguration (DAR) involves the real-time adjustment of airspace boundaries, to accommodate changing traffic patterns, weather conditions, or security concerns within a U-space airspace volume in controlled airspace. An AI could play the role of a DAR Manager by leveraging its capabilities in data analysis, pattern recognition, predictive modelling, and decision-making. Here's how an AI could fulfil this role:

- **Data Collection and Processing:** The AI would gather data from various sources on both the UTM and ATM sides as weather nowcast and forecast, flight plans and U-plans, radar data and ADS/B, and historical flight patterns, variation of population density, events and circumstances not depending from ATM/UTM but from other sources (natural, social events that can influence the operations of UAS in a U-space airspace volume), variation of CNS coverage. This data would be processed in real-time to provide a comprehensive understanding of the current airspace situation. Table 3 shows the main services from which data can be collected. Data could be collected through Application programming interfaces (APIs) allowing AI systems to directly access data from ATM and UTM systems (e.g., from CISP and USSP), and in general from the U-space ecosystem. One of the most effective processing techniques to support dynamic airspace reconfiguration while minimising the impact on existing routes and flight plans might be the use of multi-objective optimisation algorithms, often associated with game theory or multi-objective linear programming.

These algorithms could consider multiple factors simultaneously, such as minimising flight delays, reducing fuel consumption or battery capacity (case of many UAS), maximising overall system efficiency, and, in the specific case, minimising the impact on existing routes and U-plan.

Table 3. U-space data to be processed by AI.

Services	Data
UAS Flight Authorisation Service	U-plans: flight plans for flying in U-space airspace, include geometries and time limits of operations.
Geo-awareness Service	Information on operational conditions, airspace limitations or existing time restrictions (static or dynamic).
Network Identification Service	Information regarding identification of all UASs, as well their position in U-space airspace. Data include: - UAS operator registration number, - unique serial number of the unmanned aircraft or, - geographical position of the UAS, its altitude above mean sea level and its height above the surface or take-off point; - the route course measured clockwise from true north and the ground speed of the UAS; - position of the remote pilot or, if not available, the take-off point.
Traffic Information Service	Information on any other conspicuous air traffic, that may be in proximity to the position or intended route of the UAS flight (manned and unmanned). Data include: - position, - time of report, - speed, - heading or direction, - emergency status of aircraft, when known.
Weather Information Service	Weather data, provided by trusted sources, to maintain safety and support operational decisions of other U-space services, with forecast and nowcast. Data include as minimum: - wind direction measured clockwise through the true north and speed in metres per second, including gusts, - the height of the lowest broken or overcast layer in hundreds of feet above ground level, - visibility in metres and kilometres, - temperature and dew point, - indicators of convective activity and precipitation, - the location and time of the observation, or the valid times and locations of the forecast, - appropriate QNH with geographical location of its applicability.

Conformance Monitoring Service	Information regarding deviation from the flight authorisation and U-plan.

- **Pattern Recognition and Prediction:** Using advanced machine learning algorithms, the AI would identify patterns and trends in the data to predict future airspace congestion, weather disruptions, or other relevant factors that may require airspace reconfiguration. Pattern recognition involves the identification of recurring structures or trends within a dataset. In the context of airspace management, this could include identifying recurring congestion patterns, such as increased traffic during peak travel times, while prediction refers to the ability to forecast future events or conditions based on historical data and identified patterns. For example, predicting future congestion based on historical traffic patterns and expected changes in air travel demand. For instance, the AI may recognise that airspace congestion tends to increase during certain times of the day, such as morning rush hours or holiday seasons.
  Weather conditions also play an important role in airspace management, as bad weather can cause delays and route deviations. AI can analyse historical weather data along with flight data to anticipate potential disruptions, such as thunderstorms or fog, and their impact on airspace congestion. In particular, in those areas of U-space where major weather phenomena could divert routes or manned traffic approaches, and thus require a DAR.
  In addition to traffic and weather data, it is important to include factors such as special events, air traffic controller strikes, or changes in flight rules. For example, AI can predict increased congestion and the need to reconfigure airspace during a major international summit or political event, based on historical data from similar occasions. (e.g., thanks to geo-awareness service data and dynamic geography, such as NOTAMs).
  The problem in the specific case of DAR in the U-space environment is that we currently have little data on U-space use, coming from European trials without a true distribution of real case histories in urban spaces or controlled airspaces.
- **Scenario modelling:** The AI would simulate different scenarios based on expected changes in air traffic flow, weather conditions, and other variables during a DAR request. This would make it possible to assess the potential impact of different reconfiguration strategies and identify the most effective course of action. Modelling scenarios, considering various U-plans, the characteristics of UAS in place at that time within a U-space airspace, could facilitate DARM in the "design" phase of airspace reconfiguration, optimising airspace capacity and minimising the impact on other operations in the U-space that are not in the vicinity of reconfiguration volumes. Scenario modelling could take place through Hybrid Simulation Approaches: AI can combine multiple simulation techniques, such as discrete-event simulation, continuous simulation, and agent-based modelling, to fully capture different aspects of the airspace environment. This hybrid approach allows for a more nuanced exploration of potential scenarios and their implications.
- **Decision Support:** Based on the analysis of current data and predicted scenarios, the AI would provide recommendations to DARM on the optimal reconfiguration of airspace boundaries, routes, and regulations. These recommendations would take into account factors such as safety, efficiency, and regulatory compliance.

- **Real-time Adaptation:** As the situation evolves, the AI would continuously monitor incoming data and adjust its recommendations accordingly. This would enable it to respond quickly to changing conditions and ensure the smooth operation of the airspace system.

2.4.4 TRL

The case study is currently at **TRL 1**, characterised by a preliminary high-level conceptual description. Minimal details have been provided, sufficient to outline an initial idea of the concept.

2.5 Case Study 4: Dynamic Allocation of Traffic between ATCO and System

2.5.1 Purpose

The ATC Real Ground-breaking Operational System (ARGOS) is a system entirely designed and developed internally by EUROCONTROL MUAC with the aim to support ATCOs in managing traffic in their sectors by means of a dynamic allocation of airspace management between the ATCO and the system in en-route airspace.

By 2030, when air traffic has increased by more than 30% compared to today's traffic, EUROCONTROL MUAC's ambition is to safely handle that traffic with the same number of ATCOs as today. To this aim, automation is key. MUAC's Automation Strategy consists of 3 long-term objectives:

- (Obj1) Fully automated pre-tactical phase,
- (Obj2) Automated decision making and execution support for complex tactical scenarios and
- (Obj3) Fully automated separation assurance in the basic tactical scenarios.

The ATC Real Groundbreaking Operational System (ARGOS) is the key system in progressing on Obj2 and Obj3.

2.5.2 Objectives

ARGOS is able to detect potential threats with a look ahead of 8 minutes and is able to adopt specific interaction avoidance / separation assurance strategies based on lateral or vertical manoeuvres, on the basis of a deterministic model derived from the strategies currently used by the ATCOs. The separation assurance logic involves the two aircraft involved in the potential interaction and takes into account the rest of the traffic that might be affected by the resolution strategy and that are within the ARGOS look ahead.

The system includes an independent ARGOS-Checker (Check-ARGOS = CARGOS), that is a completely distinct sub-system with different logics. Such a tool works next to ARGOS and checks whether the plan proposed by ARGOS is acceptable. Its consent is needed before the ARGOS Plan is automatically executed (or proposed to the ATCO). A second functionality of CARGOS could be to check that the overall ARGOS Plan (all flights) is not generating a "complex" situation.

Within the scope of the ARGOS Project, it is not the intention to change current staffing levels at the sector (2 ATCOs/sector). The intention is to increase sector-productivity so that fewer sectors are required in basic traffic situations, and more sectors can be opened in more complex traffic conditions.

At the same time, this also leads to workload reduction and possible Safety and ATCO Productivity improvement in high traffic periods.

2.5.3 Automation Role and Techniques

ARGOS will be fed by the FDPS (Flight Data Processing System) and SDPS (Surveillance Data Processing System) and will issue commands/suggestions to the CWP. On the CWP, the ATCO can decide to let the system issue the clearances automatically (using CPDLC), or take its suggestions (proposed plan) and work the traffic him/herself. The automation brought by ARGOS is based on the following algorithms:

- adherence to ATC (TFL, DCT TO, TRANSFER),
- conflict detection and resolution,
- complexity detection and dispersion.

Operationally, ARGOS will ensure that the clearances issued will be such that:

- flight exit conditions (as determined by the FDPS) are met;
- no conflicts occur within the sector;
- prohibited areas are not penetrated;
- flights are transferred conflict free and sequenced (LoA conditions met).

In addition, ARGOS will be able to distinguish basic and non-basic traffic scenarios and to warn the ATCO when it gets out of its comfort zone – thus requesting ATCO assistance. In fact, ARGOS is supposed to be operated in three different modes of operations, corresponding to different levels of automation and different operational constraints, roles and procedures. The three modes of operations are indicated with the following names and codes:

- Decision Support Tool mode of operations (L3),
- Hybrid mode of operations (L5) and
- Automated mode of operations (L8)

The code L0 is given to the current mode of operations (no-ARGOS). These three modes are currently being put in operations.

The concept at Level 8 assumes a full deployment of Controller Pilot Data Link Communication (CPDLC) capabilities on the ground and on-board the aircraft. The other operational modes can still be applied in case of non CPDLC equipped traffic, with the limitation that the aircraft without CPLCD capabilities can just profit from ARGOS as a decision support tool (L3).

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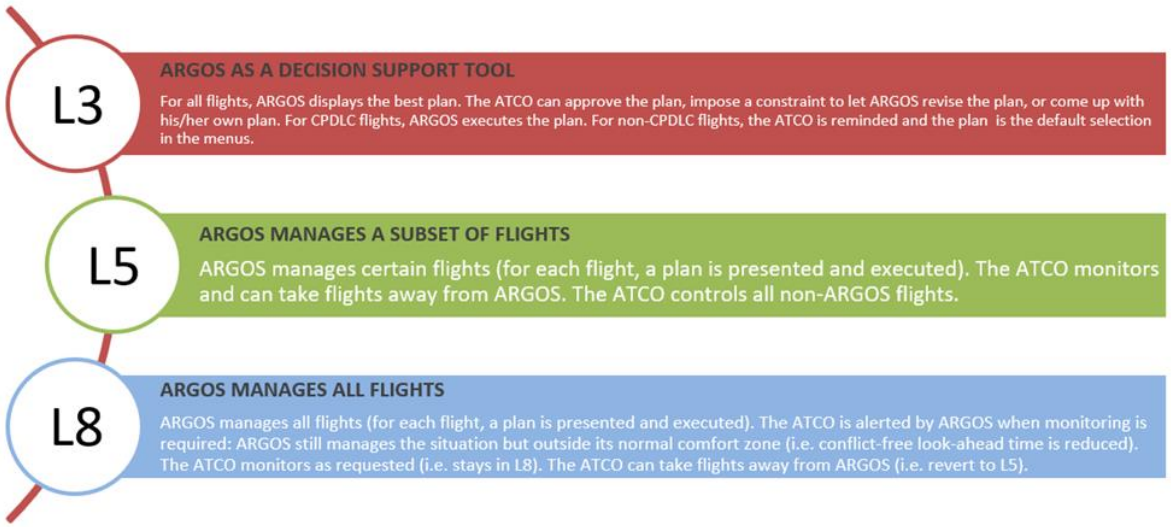

Figure 8. Modes of operations of ARGOS.

Decision support tool mode of operations (L3)

L3 is the mode of operations where ARGOS is used and managed as a Decision Support Tool (DST).

In the literature, one can find multiple definitions of Decision Support Tools or Decision Support Systems. In this report we make reference to the following one that is strictly related to the ATM systems: “DSTs provide system users (air traffic controllers, traffic flow managers, technical operations personnel) with recommended solutions or methods to evaluate potential solutions before they are implemented. […] DSTs can provide valuable assistance by helping users evaluate, select, and implement effective solutions.”

Valuable examples of DST are already deployed in several operational control rooms around the world, including the Medium-Term Conflict Detection (MTCD) and the Arrival, Departure and Surface Management Systems (AMAN, DMAN and SMAN). In the specific case of MUAC, the list of DST already in use includes the VERA tool, the long probe, the CFL Menu shading, LORD and the DCT TOP 10 providing the list of most probable next route point in the Route Menu.

The following diagram shows the operating method that is expected to be adopted when ARGOS is used in DST Mode (L3).

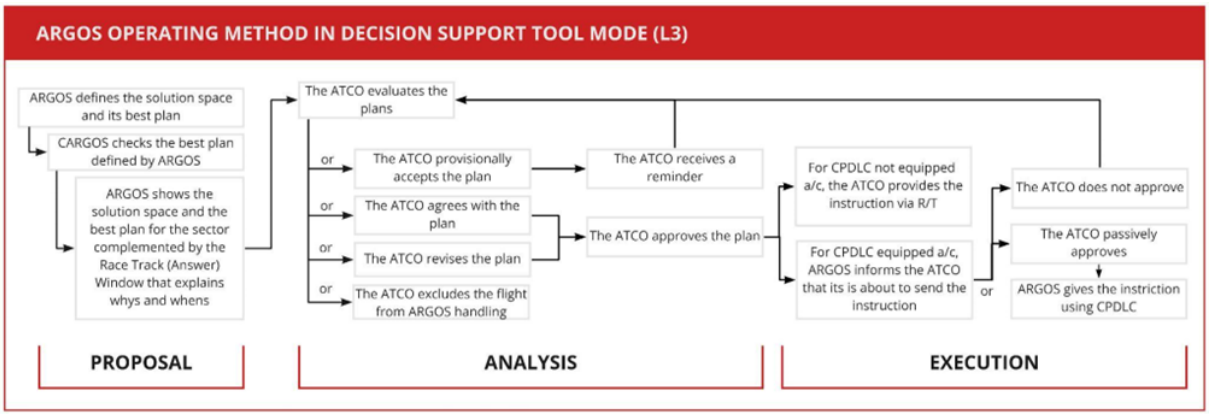

Figure 9. ARGOS operating method in decision support tool mode (L3).

In this case, after evaluating the overall traffic situation, ARGOS proposes to the ATCO its best plan for the traffic in the sector. The plan consists of a set of multiple timed actions. For each flight, it shows a solution space and the suggestion for the plan to be applied. The main building blocks of ARGOS decision support are, in fact, conflict and solution spaces, i.e. 'ranges' of options that are (dis)advantageous. Among the “compatible” solutions, the system then highlights the optimal (i.e. ecological & economical) decision.

The ATCO knows that the proposal displayed has already been successfully checked by CARGOS. The ATCO can approve the plan (also tentatively), impose a constraint to let ARGOS revise the plan, or come up with his/her own plan. In the latter case, the controller comes back to the full “traditional” control of the flight. If the ARGOS plan is approved (although after the controller's revision), for CPDLC flights, ARGOS executes the plan sending the clearances to the traffic at the right time. For non-CPDLC flights, the ATCO is reminded and the agreed plan is the default selection in the menus of the CWP.

Hybrid mode of operations (L5)

The hybrid mode of operations (L5) applies when certain flights in a sector are managed by the controller with the support of ARGOS (like in L3), while other flights are directly managed by ARGOS (for each of these flights, a plan is presented and executed by ARGOS with no intervention of the controller). The ATCOs (Executive and Coordinating Controller) monitor ARGOS and can take flights away from its management.

The following diagram shows the operating method that is expected to be adopted when ARGOS is used in hybrid mode (L5). Since in hybrid mode the tasks of traffic management are shared between ARGOS and the ATCO, an interesting co-agency emerges among the two, to which specific communication and negotiation activities are associated. In particular, the different recurrent phases of cooperation (planning, analysis, execution) already identified in the DST mode of operations (L3) are associated to different activities in the hybrid mode (L5) and in addition a fourth phase, concerning the alerting, is identified as relevant:

- in the proposal phase, ARGOS proposes how to share the traffic among them in a nominal situation, or vice-versa the ATCO proposes to ARGOS to manage specific flights
- in the analysis phase, the subject who has received the proposal (either one of the ATCOs or ARGOS) evaluates its feasibility to then come to the conclusion to accept or not

- in the alert phase, ARGOS asks the ATCO to monitor a situation and/or to intervene.

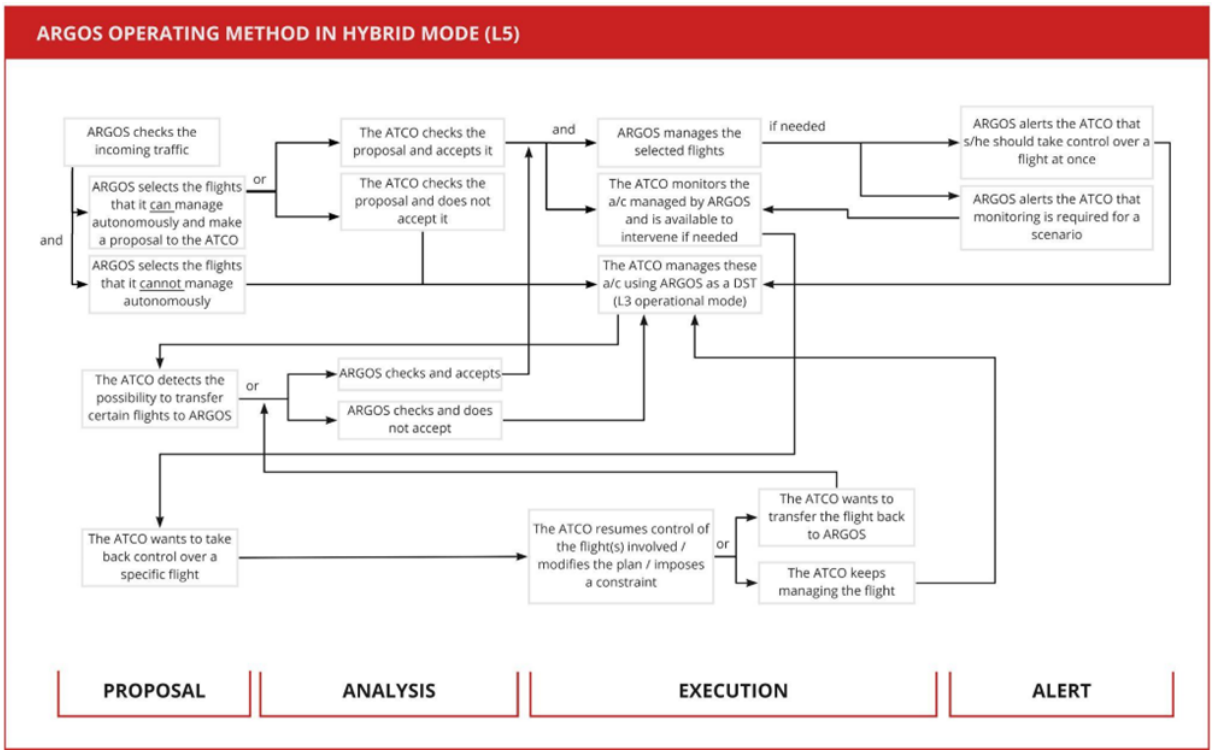

Figure 10. ARGOS operating method in hybrid mode (L5).

Automated mode of operations (L8)

L8 is the mode with the highest level of automation among the modes of operation of ARGOS. At L8, ARGOS manages all the flights (for each flight, a plan is presented and executed).

Once the Automated mode (L8) is activated, ARGOS defines and executes a plan for each flight. It may also make the plan available to the ATCO, on request. The staff is reduced, as a part of the available ATCOs remain in the OPS room at disposal to intervene if requested by ARGOS, while the others can have a rest. The ATCOs in the OPS room do not have a specific monitoring task, unless their active monitoring or intervention is requested by the system.

The ATCO is alerted by ARGOS when monitoring is required: ARGOS still manages the situation but outside its normal comfort zone (i.e. conflict-free look-ahead time and/or separation buffer is reduced). The ATCO monitors as requested (i.e. stays in L8) or can take flights away from ARGOS (i.e. revert to L5).

Note: At this stage of development of the concept, L8 is limited to sectors with basic traffic situations. This assumes that when ARGOS makes incorrect decisions, and would create hazardous situations, other mechanisms (e.g. STCA with extended safety margins) will timely warn the ATCO and allow him/her to get into the picture and resolve the situation.

Transitions among modes of operations

Since three different modes of operations are envisaged, an important aspect of the ARGOS operational concept concerns the activation and deactivation of the different modes and hence the transition among them. As anticipated, the activation and deactivation of the different modes is a responsibility of the Tactical Supervisor (TactSup), who makes the decision per each sector, based (also) on suggestions coming from ARGOS and, then, shares it with each of the concerned sectors via the HMI.

The following diagram offers a generic representation of the process followed for the activation and deactivation of each mode of operation.

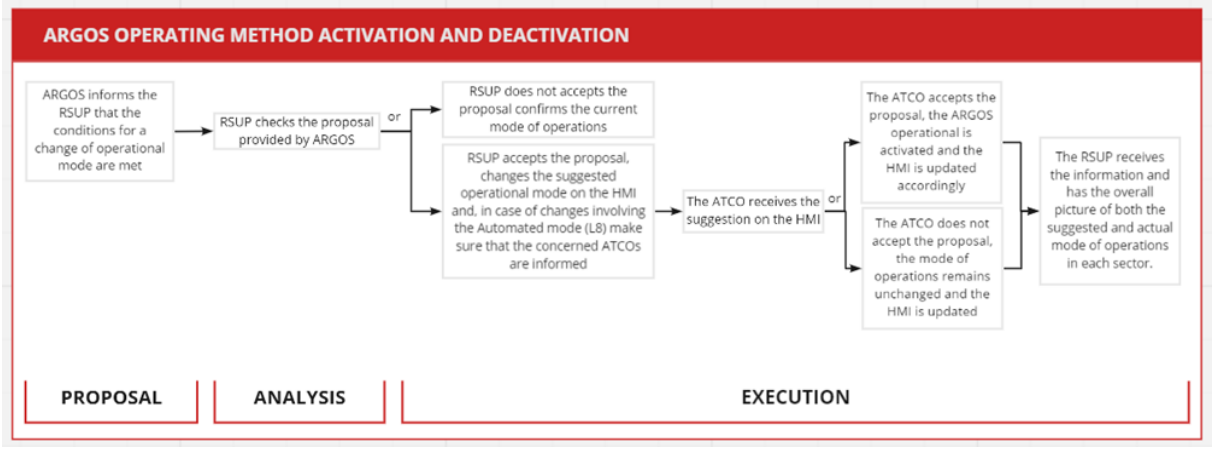

Figure 11. ARGOS activation and deactivation of each mode of operation.

The analysis of the activation process is particularly interesting when considering the Hybrid mode of operations (L5). Actually, the activation may start from a previous DST mode (L3), with an increase of the level of automation, or conversely may be activated as a consequence of a deactivation of the Automated mode (L8), when some flights are taken away from ARGOS.

Activation of the Hybrid mode (L5) starting from the DST mode (L3)

The decision of activating the Hybrid mode of operations (L5) starting from the DST mode of operations (L3) is made by the RSup (more specifically by the TactSup), who is supposed to have a dedicated working position where a comprehensive map of the OPS room shows the ARGOS operational mode/s suggested and active in each sector.

While in L3, ARGOS envisages the possibility to change the operational mode, switching to the Hybrid one (L5) for a specific sector, as a set of (predefined) conditions of traffic complexity are satisfied, and provides such suggestion to the TactSup, who checks the proposal and may decide to explicitly inform the ATCOs - via a dedicated HMI on his/her working position - that the operational mode in the sector can be the hybrid one. The ATCOs receive the information on their CWP as a suggestion and they may decide whether to accept it.

If the ATCOs do not accept to switch to the hybrid mode, the ARGOS operational mode will remain L3 and both the CWP and the RSup working positions will keep track and make evident that for that specific sector the suggested mode is L5 while the active one is L3.

Conversely, if the ATCOs agree to switch to the hybrid operational mode, ARGOS selects the flights that it is able to handle, basing the judgement on certain predefined rules. These rules allow ARGOS to distinguish between “complex traffic” and “basic traffic”, with the latter being the only traffic that may be assumed and managed by the system.

The ATCO (Executive Controller) is advised on his/her CWP that ARGOS is going to take the “basic” flights. The ATCO has then the opportunity to block the transfer of the flight, or otherwise silently approve the “handover”. The same process is applied to every flight incoming in the sector: ARGOS evaluates whether the “new comer” is a good candidate to be managed by itself and alerts the controller that can block or accept the transfer.

During the operations, the ATCOs continuously monitor ARGOS and can intervene to take away one or more flights from it. In such a case, the ATCOs resume control of the flight(s) involved, modify the plan or impose a constraint.

Activation of L5 starting from L8

The activation of the hybrid mode (L5) starting from the automated mode (L8) may happen in two different situations:

- L8 pre-conditions are no longer met in general - it means that the overall conditions for being in the automated mode are not met anymore and the ATCO shall manage at least a part of the traffic (e.g. because the operating daytime of L8 is coming to its end)
- L8 pre-conditions are no longer met for specific flight/s - it means that during the operations at L8, while ARGOS manages the traffic autonomously, ARGOS realises that some traffic is not “basic” anymore and an active monitoring by the executive controller is needed.

In the first case the TactSup receives a suggestion from ARGOS to switch to the hybrid mode (L5), and changes the maximum operational mode allowed on his/her working position. This implies that the message is automatically transmitted to the CWPs of the concerned sectors and in parallel all the ATCOs are requested to resume their working positions at the concerned sectors. When ready, the ATCO changes the ARGOS operational mode on the CWP and this implies a process that is specular to the one that we have already shown for the activation of the hybrid mode (L5) from the DST mode (L3). It means that ARGOS makes a double proposal about the traffic that it can keep managing and the traffic to be transferred to the ATCO. The ATCO checks the proposal and, after approval or revision of the plan offered by ARGOS, leaves a part of the traffic under the direct management of ARGOS, while controlling directly the other part.

In the second case, i.e. when the L8 pre-conditions are no longer met for a specific flight, the system advises the ATCO through the HMI that his/her attention is needed for the highlighted traffic and in the meantime it keeps managing such traffic “out of its comfort zone”. At this stage, the ATCO starts monitoring the flight(s) highlighted by ARGOS and, if s/he judges that ARGOS is no more able to manage the situation, then the ATCO resumes control of the flight(s) involved, modifies the plan and/or imposes a constraint. At the end of this process, ARGOS will be managing some of the flights while the ATCO will be managing some others, meaning that the system will be working in L5 mode.

Activation of L3 starting from L8

It may also happen that the deactivation of the Automated mode (L8) brings to the DST mode of operations (L3) in case the ATCO judges that the situation is such that ARGOS would not be able to manage (not even) a part of the traffic autonomously.

Deactivation of ARGOS

Finally, the unfortunate event of a complete deactivation of ARGOS is also considered in case CARGOS detects and alerts the ATCO and the TactSup that ARGOS is not working properly. In this case the TactSup may decide to stop ARGOS or keep it in the background with the effect of reaching a no-ARGOS (L0) mode of operations. It is to be noticed that in L3 or in L5 a malfunction of ARGOS can be detected by either the ATCOs and/or CARGOS, while in L8 most of the responsibility for detecting malfunctions in ARGOS and informing the TactSup and the ATCOs is attributed to CARGOS.

2.5.4 TRL

Overall the case study is currently at **TRL 4**, characterised by component validation in laboratory conditions. Nevertheless some of the components have a higher TRL, in particular those to be used for the L3 mode of operations.

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3 Human Factors Change Analysis

This chapter reports a brief overview of the main aspects related to the human factors analysis of the proposed case studies. Such aspects focus on the human-activity impacts (in terms of changes) brought by each case study.

Section 3.1 presents the approach employed for the analysis, while the results are reported in section 3.2.

3.1 Approach

The approach for the human factors analysis aims at highlighting the human-activity impacts brought by each case study. Such impacts are intended as changes with respect to the human aspects in the baseline solution or more generally the current ATM operations, and are assessed with respect to the following human factors areas for each human actor [12]:

- **Key Role, Tasks and Responsibilities** – They specify:
    - *Role*, which is the purpose that the human actor has, i.e., the characteristic function performed by the actor.
    - *Tasks*, which are composites of related activities (perceptions, decisions, and responses) performed by the reference human actor for an immediate purpose. They may be associated with a task demand, that is the amount of effort required to perform a task (influenced by workload, time pressure, distractions, etc.).
    - *Responsibilities*, which are the things that are an actor's duty to deal with and to be achieved.
- **Key Tools** – These represent the set of hardware and software items (including HMIs) employed by the human actor to perform the tasks.
- **Communication** – It refers to the timely process of passing information between people completely and accurately so that it is received and understood. It includes communication methods, e.g., from verbal communication to computer-mediated communication.
- **Organisation and Planning** – It refers to organisational management, including the management of staff and resources.

The proposed approach is applied for each case study by:

- identifying the reference human actors involved in the case study; and
- evaluating the change of every human factors area for each actor with respect to the baseline.

The change is evaluated on a scale of 1 to 5, in increasing order of impact, where 1 represents no impact and 5 represents a very high impact, as shown in Table 4.

Table 4. Scale for human factors change evaluation [15].

Value	Human-Factor Change Impact
1	**No impact** – A negligible change occurs with respect to the reference human aspect.
2	**Minimal impact** – A minor change occurs with respect to the reference human aspect.
3	**Moderate impact** – A moderate change occurs with respect to the reference human aspect.
4	**High impact** – A noticeable change occurs with respect to the reference human aspect.
5	**Very High impact** – A very significant change occurs with respect to the reference human aspect.

3.2 Results

This section reports the results of the human factors analysis of each case study.

3.2.1 Case Study 1

The proposed case study aims at supporting **dynamic sectorisation** process, in which [13]:

- a number of elementary air volumes are defined;
- a short-term capacity demand prediction is generated in a real-time environment using fast-time simulation of planned traffic;
- the ATC sectors are then formed as the most suitable combination of the elementary sectors to meet the capacity demand at a certain moment.

For dynamic sectorisation, the current operating method (baseline) is represented by the Dynamic Capacity Management (DCM) delivered by P04.07.07 solution [14]. In this solution, a decision support tool forecasts the expected performance of the ATM system from several months before the day of operation to "D-1 day". Forecasts are based on the processing of a large volume of historical data obtained from multiple sources of information. An optimisation algorithm provides the necessary outputs for decision-making. The involved human actor is the person responsible for operations, i.e., the **OPS Supervisor – Flow Manager**, who selects an optimum sector configuration and its distribution of human resources. Starting from sector families defined at the ATC Centre and applying the optimisation algorithm, the OPS Supervisor – Flow Manager may apply different sources of information: historical traffic data; a mix of real traffic data and historical data; uniquely real traffic data.

The proposed case study introduces a new optimisation algorithm for dynamic sectorisation, to explicitly model also the behaviour of ATCOs and consider their workload for the sector optimisation. However, the case study does not significantly affect the human operations with respect to the baseline P04.07.07 solution, keeping mostly unchanged the human aspects of the OPS Supervisor – Flow Manager.

Based on the aforementioned considerations, the following impacts are expected for the human-performance areas regarding the OPS Supervisor – Flow Manager, as shown in Figure 12:

- **Key Role, Tasks and Responsibilities –** *Minimal Impact (2/5)*
  The role, tasks and responsibilities of the OPS Supervisor – Flow Manager do not change. A minor change may be present for the task of checking the results of the sector optimisation tool, since the OPS Supervisor – Flow Manager also has to review the workload forecasts.
- **Key Tools –** *Minimal Impact (2/5)*
  There is not a new tool for optimisation since only a new algorithm is applied in the tool. Some minor changes may regard the HMI (e.g., to report workload forecasts for ATCOs).
- **Communication –** *No impact (1/5)*
  The communications of the OPS Supervisor – Flow Manager are not affected.
- **Organisation and Planning –** *No impact (1/5)*
  The organisation and planning of the OPS Supervisor – Flow Manager are not affected.

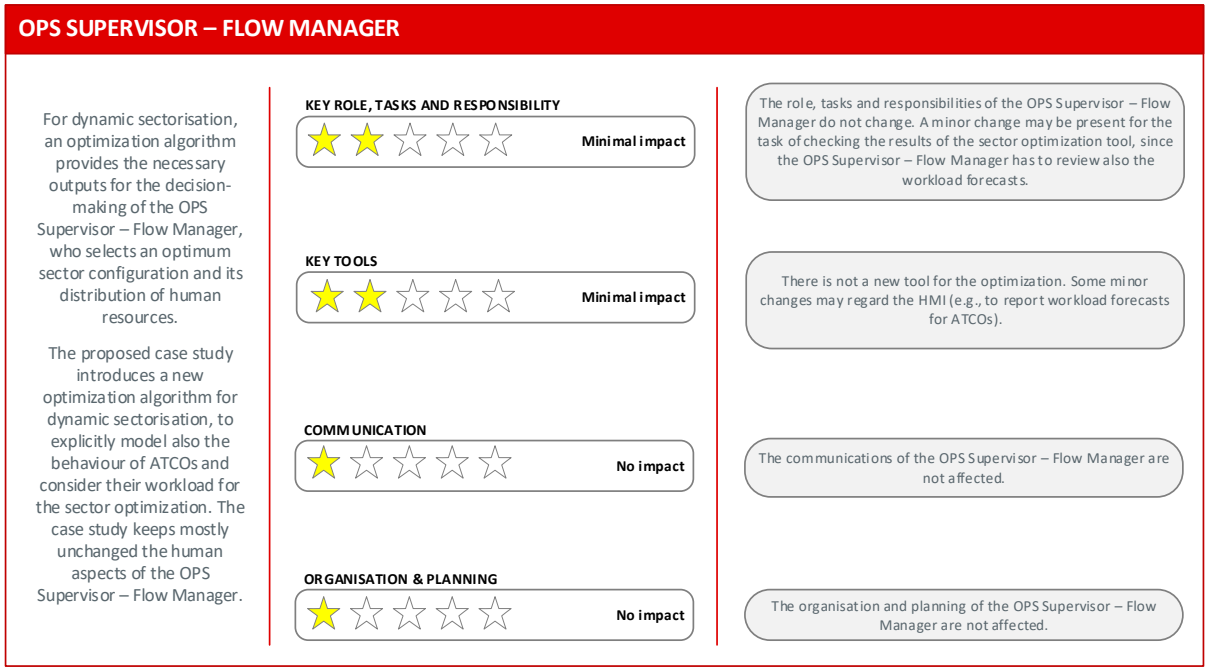

Figure 12. Human impacts for the OPS Supervisor – Flow Manager in Dynamic Airspace Sectoring (case study 1).

3.2.2 Case Study 2

As human actors, this case study involves both **Planner Controllers** and **Executive Controllers** of the considered sectors, who act through **Controller Working Positions**. In the proposed operational environment of the solution, the DA will support the ATCO (PC and EC) perception by means of:

- **an alert about conflict detection**, with possible classification of the conflict;
- **a set of proposals for conflict resolution in line with solutions the ATCO would have identified on her/his own** (i.e., in absence of the tool).

In the baseline, the ATCO pair work as follows:

- the PC plans the flights in the sector, assesses the conflict detection performed by the Tactical Conflict Detection and Resolution (TCT) within a 12 minutes horizon time, and manually defines conflict resolutions without any support;
- the EC acts in coordination with the PC to assess remaining in-sector conflicts and executes resolution instructions, which are sent by the EC to the aircraft crews (via voice) or that are coordinated with the upstream sector.

With the introduction of the AI-powered DA, the following changes will regard the reference human operators:

- the DA provides suggestions for tactical conflict resolution to the ATCOs;
- the conflict perception of the ATCOs is supported by the DA, with conflict detection (including type of conflict) and resolution proposals;
- the resolution proposals are delivered to the ATCOs sufficiently in advance (at least 12 minutes for the time horizon) as soon as the conflict is detected, to allow the ATCOs to process the conflict detection and the resolution proposals[4];
- the resolution proposals are dynamically updated during traffic evolution (unless a resolution is selected).
- the PC plans the flights in the sector, and checks the inputs of the DA (detected conflicts and resolution proposals);
- the EC, in coordination with the PC, assesses resolution instructions (provided by the DA), that are sent by the EC to the aircraft crews (via voice) or that are coordinated with the upstream sector.

Based on the aforementioned considerations, the following impacts are expected for the human-performance areas regarding both PCs and ECs, as shown in Figure 13:

- **Key Role, Tasks and Responsibilities –** *Moderate Impact (3/5)*
  The role and responsibilities of ATCOs (PCs and ECs) do not change. However, the introduction of the DA introduces additional tasks, i.e., to check the DA's information (conflict detection and resolution proposals) and to build their own assessments based on those inputs.
- **Key Tools –** *Very High Impact (5/5)*
  The AI-powered DA is a new advanced tool that supports ATCOs' perceptions for conflict resolution, with a novel specific HMI.
- **Communication –** *No Impact (1/5)*
  The DA acts as a decision support tool for conflict resolution. PCs and ECs communications are not affected.
- **Organisation and Planning –** *No Impact (1/5)*

[4] The AI-based conflict resolution algorithm should be able to provide a resolution that will not create other conflicts in the sector within next 8 minutes. In any case, the detection of the conflict is repeated minimun every 4 seconds: thus, if another conflict is created, it is detected and the conflict resolution solver is able to identify a new solution proposal.

The DA acts as a decision support tool for conflict resolution. PCs and ECs organisation/planning are not affected.

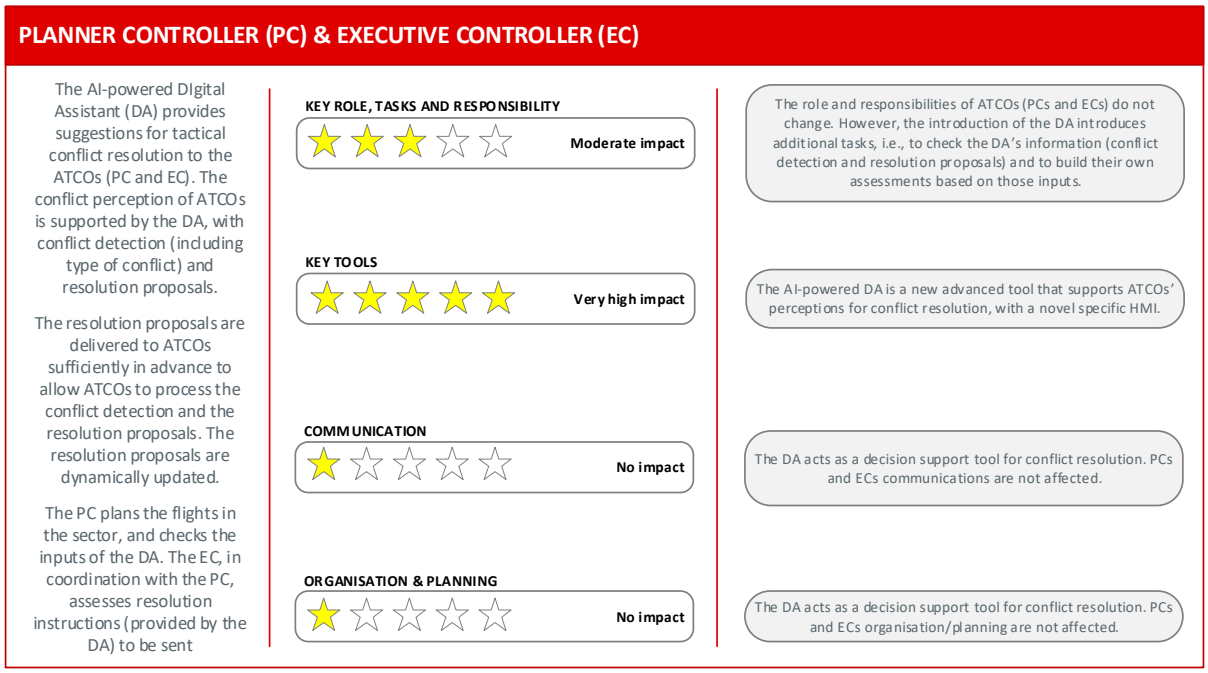

Figure 13. Human impacts for the PC and the EC in the AI-powered Digital Assistant for TMA (case study 2).

3.2.3 Case Study 3

The **Dynamic Airspace Reconfiguration Manager** (DARM) is an ATC role responsible for providing the DAR service, which involves modifying the geographical boundaries of U-space volumes based on requests from ATC and USSP. The DARM must continuously monitor the ATM-U-space Shared Airspace (AUSA) and maintain comprehensive situational awareness of both manned operations receiving ATC services and UAS operations. **The introduction of an advanced automation tool for the DAR service will impact the DARM tasks and responsibilities**. The implementation of this new tool will bring about significant changes, surpassing the baseline that has so far been used exclusively in project contexts as AURA project (PJ34-W3) and ENSURE. Specifically, the following changes are preliminarily anticipated, considering the TRL 1 level of the case study, as shown in Figure 14:

- **Key Role, Tasks and Responsibilities –** *Moderate Impact (3/5)*
  The role of the ATCO and the DARM does not change. However, the introduction of an advanced support tool for DAR involves additional tasks and responsibilities. The DARM will be required to review the solutions and plans proposed by the tool and to act promptly.
- **Key Tools –** *Very High Impact (5/5)*
  The new advanced tool plays a significant role, not previously implemented. It primarily acts as a decision support tool for the DARM. On the one hand, it continuously analyses numerous data from different sources, adapting in real time; on the other hand, it models scenarios when a DAR request involving a portion of U-space is made. The DARM then reviews the proposed solutions and ultimately selects the optimal one suggested by the tool.
- **Communication –** *Minimal Impact (2/5)*

The advanced tool works as a decision support tool for the DARM. It interacts with the CIS platform and will communicate to it which proposed solution has been selected by the DARM. The DAR volume will then be shared with the CIS and subsequently with the USS as dynamic geographical information through the geo-awareness service.

- **Organisation and Planning –** *No Impact (1/5)*.

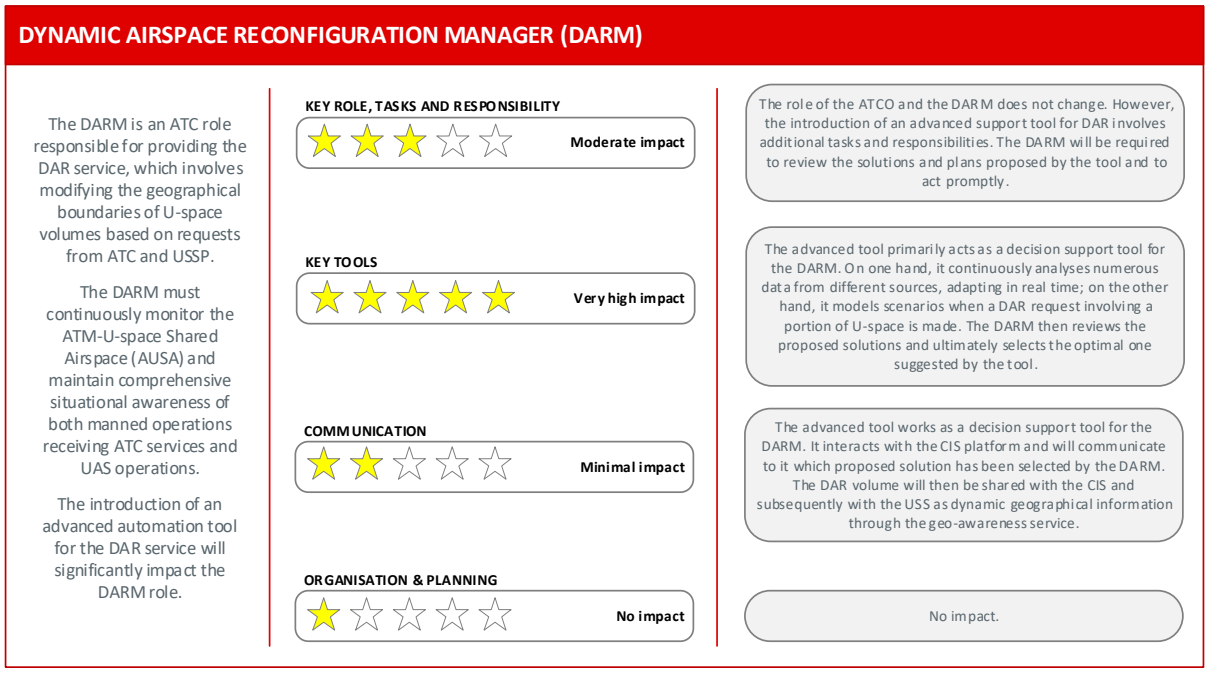

Figure 14. Human impacts for the DARM in the Dynamic Airspace Reconfiguration Service for U-Space (case study 3).

3.2.4 Case Study 4

The **Current Operations unit (CO)** (baseline situation) is responsible for day-to-day operations of the MUAC OPS room providing safe and efficient ATSs to civil and military airspace users in accordance with legal requirements; developing and enhancing MUAC capacity; managing operational documentation; validating and accepting changes to the operational systems and investigating and reporting on operational incidents. It includes Airspace, Systems & Procedures (ASP); Planning & Roster Office (PRO); Capacity Management (CAP); Flow Management (FM); Duty Supervisors (DS); Room Supervisors (RS); ATCOs (AT); Executive Operational Support (EOS). The unit is deeply involved in the validation and acceptance of ARGOS prior to its introduction into the OPS Room. It is also responsible for accepting it in the OPS room, for the day-to-day operations and for planning the roaster. This last activity is particularly concerned in case of ARGOS being used in automated mode (L8).

Two roles within the CO unit are particularly affected by the introduction of ARGOS, namely the **Room Supervisor (RSUP)** and the **Executive and Coordinator ATCOs** (here referred to with the general term ATCOs). The introduction of ARGOS implies changes in their roles, tasks and responsibilities, in the tools they use, in the way they communicate as well as in the organisation and planning of their work, that are summarised in the following schemes.

Room Supervisor

As evident from the scheme below, **the Room Supervisor (RSUP) will be highly impacted by the introduction of ARGOS.**

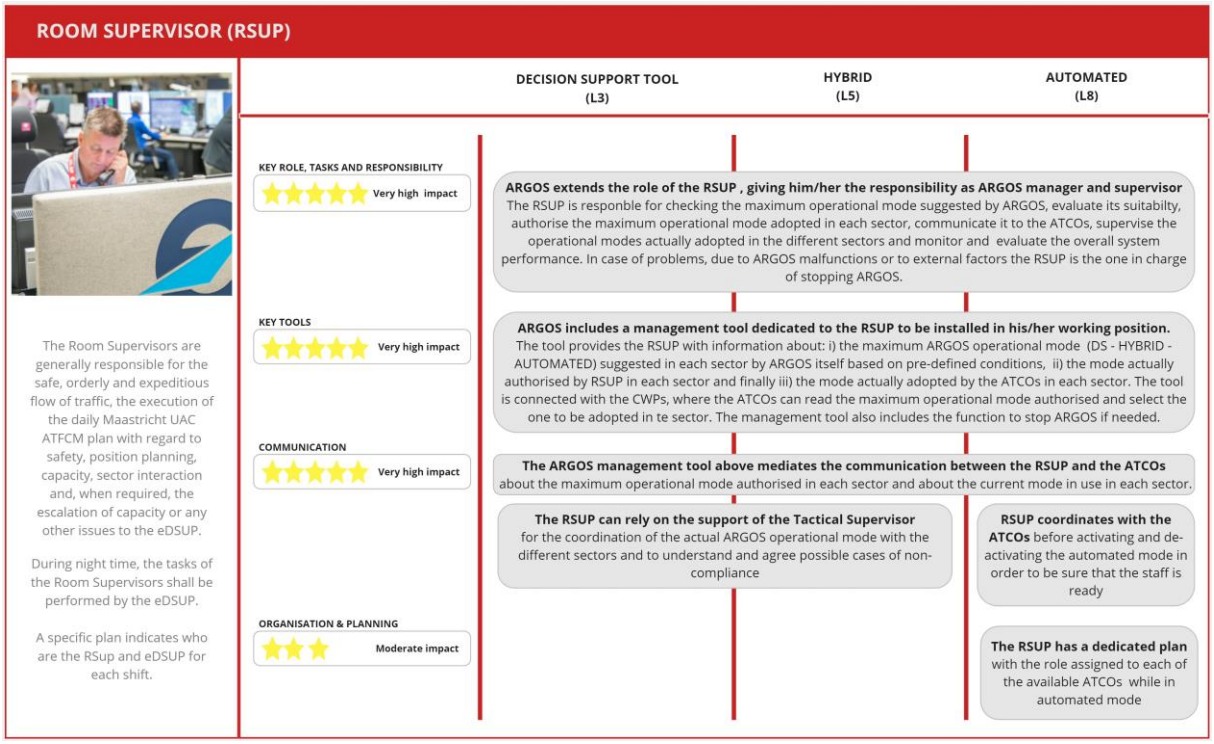

Figure 15. Human impacts for the Room Supervisor in ARGOS.

In particular, the role of the RSUP is expected to be highly impacted, as the introduction of the new system will imply a significant extension of his/her role and the addition of a set of new tasks. In the new scenario the RSUP performs the duty of ARGOS manager and is in charge of deciding the ARGOS mode of operations to be used in each sector, monitoring its behaviour and also handling the transitions between modes of operations. As a consequence, a major impact is expected also in the key tools at his/her disposal as additional and dedicated tools and a dashboard will be provided to support monitoring ARGOS, changing the mode of operations and coordinating with the ATCOS managing the sectors and working in operational CWPs. The new tools will in a large part mediate the cooperation and coordination with the ATCOs, thus highlighting important changes also in the communication with other roles, not only in terms of tools but also in terms of contents.

If the impact on role, tasks and responsibilities, key tools and communication is generally quite high for the RSUP for the reasons above mentioned, the same effect does not emerge while analysing the impact on organisation and planning. With reference to this aspect in fact, the impact of ARGO is limited and mainly concerns the L8 mode of operations, requiring the RSUP to have and manage a dedicated plan for available ATCOs.

Executive and Coordinator ATCOs

The role of **Executive and Coordinator ATCOs will be highly impacted by the introduction of ARGOS.**

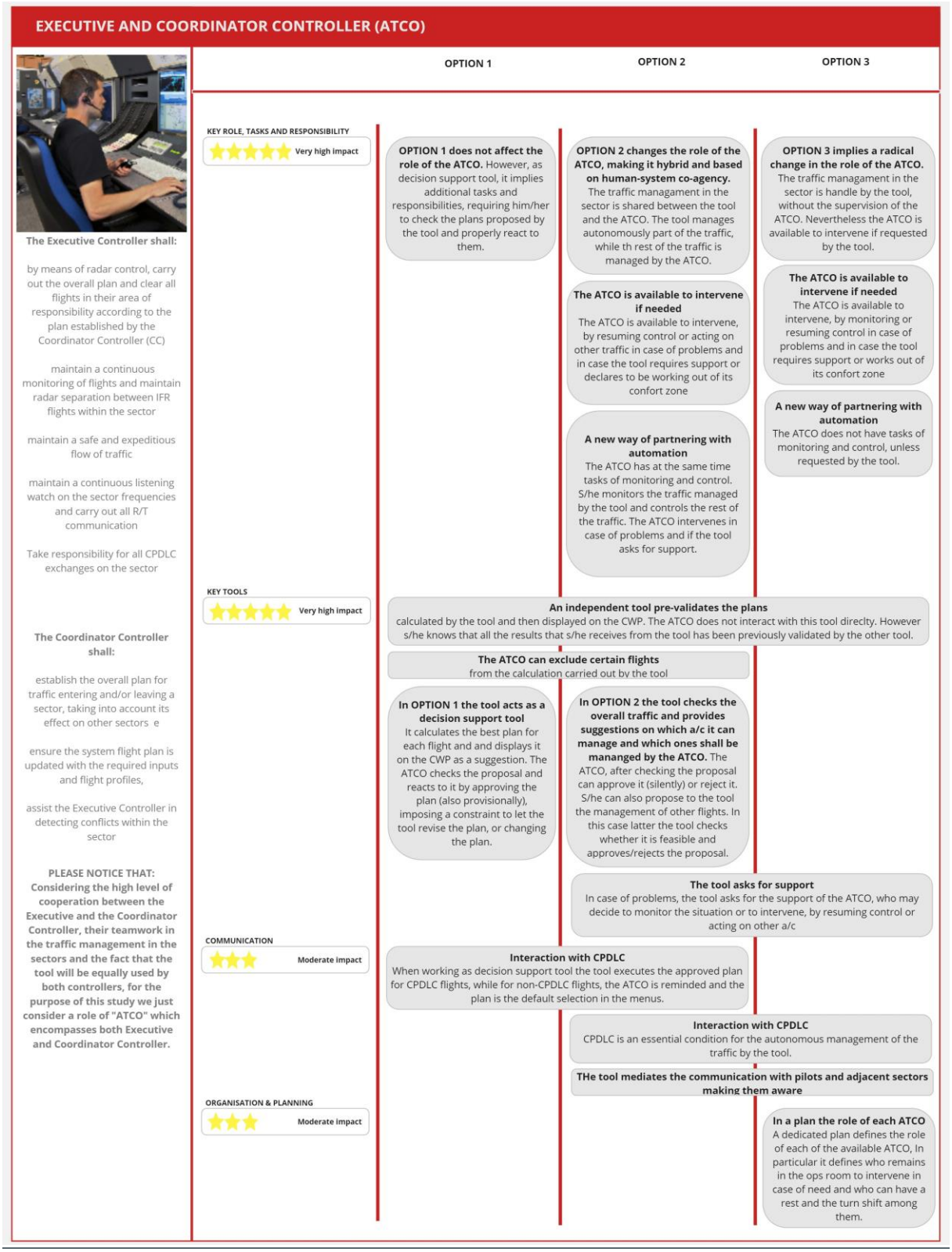

Figure 16. Human impacts for the ATCO in ARGOS.

As described in the previous scheme, overall the role of the ATCOs will be highly impacted by the introduction of ARGOS. Looking more specifically at the impact of the modes of operation it is evident that the impact is particularly high in L5 and L8, while in L3 it can be considered limited. In L3 in fact ARGOS is a decision support tool, the ATCOs shall be able to use it but this per se does not radically affect their roles, tasks or responsibilities. Different is the case of L5 and L8 where the role of the ATCOs changes significantly requiring a new kind of partnering with automation in L5 and implying just the human oversight of the system in L8. Imagining to combine the three modes of operations, thus assuming a dynamic operational scenario in which ARGOS can be used in different modes during the same shift and in different sectors at the same time, the impact expected on complexity of the roles, tasks and responsibility of the ATCOs is definitely high. This high impact on roles is reflected also in key tools, as the ATCOs will have to interact with a variety of different new tools in different ways depending on the mode of operations currently in use. This is a high impact also on skills, while the impact on communication and on organisation and planning is more limited.

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4 Level of Automation Assessment

This chapter reports the assessment of the level of automation (LOAT) of each case study.

Section 4.1 presents the approach of the assessment. Section 4.2 reports the assessment results. Section 4.3 presents some preliminary considerations about LOAT assessment, based on the results of the case studies.

4.1 Approach

For the purposes of the assessment of the levels of automation for each case study, a **functional automation-related approach** is applied. Such approach consists of the following steps (to be performed for each case study):

1. identification of the **reference functions**;
2. evaluation of the **"local" automation level** to be assigned to each reference function;

The reference functions are defined as the high-level functions related to the advanced automation capabilities within the case study. They are identified applying a **functional decomposition**, based on the detailed specification of the case studies for the automation role and techniques (reported in sections 2.2.3, 2.3.3, 2.4.3, and 2.5.3). In detail, we consider the **first-level functions** (i.e., the functional blocks at the first level of decomposition) as reference functions.

As **Levels of Automation Taxonomy (LOAT)**, the assessment employs the taxonomy proposed in [6] to evaluate both local and global automation levels. Such a taxonomy is in turn based on the LOAT proposed by S3JU [7], which has recently provided insights into contextualising different types of AI, aligning them according to various levels of automation. As depicted in Figure 17, distinct AI categories can influence diverse human-machine interaction types, contingent upon the attained level of automation in specific cognitive tasks. At all Levels there is full automation for the activities of Perception and Analysis, but there are differences where the Decision-making, the Execution of the action, and the Authority of the human operator are concerned. In detail:

- at Level 1A (EASA), AI acts as "human augmentation" with "low automation" (Level 0, S3JU), where human operators retain full decision-making and execution responsibilities;
- at Level 1B (EASA), AI functions as "human assistance" with a focus on "decision support" (Level 1, S3JU) enabling humans to make informed decisions based on overviews of feasible options provided by the system;
- at Level 2A (EASA), AI facilitates "human-AI cooperation" as a "resolution support" system (Level 2, S3JU), where humans evaluate and refine solutions proposed by automation;
- at Level 2B (EASA), AI fosters "human-AI collaboration" at a "conditional automation" level (Level 3, S3JU), allowing humans to assign tasks to either the automation or themselves;
- at Level 3A (EASA), AI operates in a "safeguarded" or "confined" automation mode (Level 4, S3JU), functioning autonomously but supervised by humans upon request or when operating outside its designated domain;
- at Level 3B (EASA), AI operates fully autonomously without human supervision (Level 5, S3JU).

Further details are available in [6].

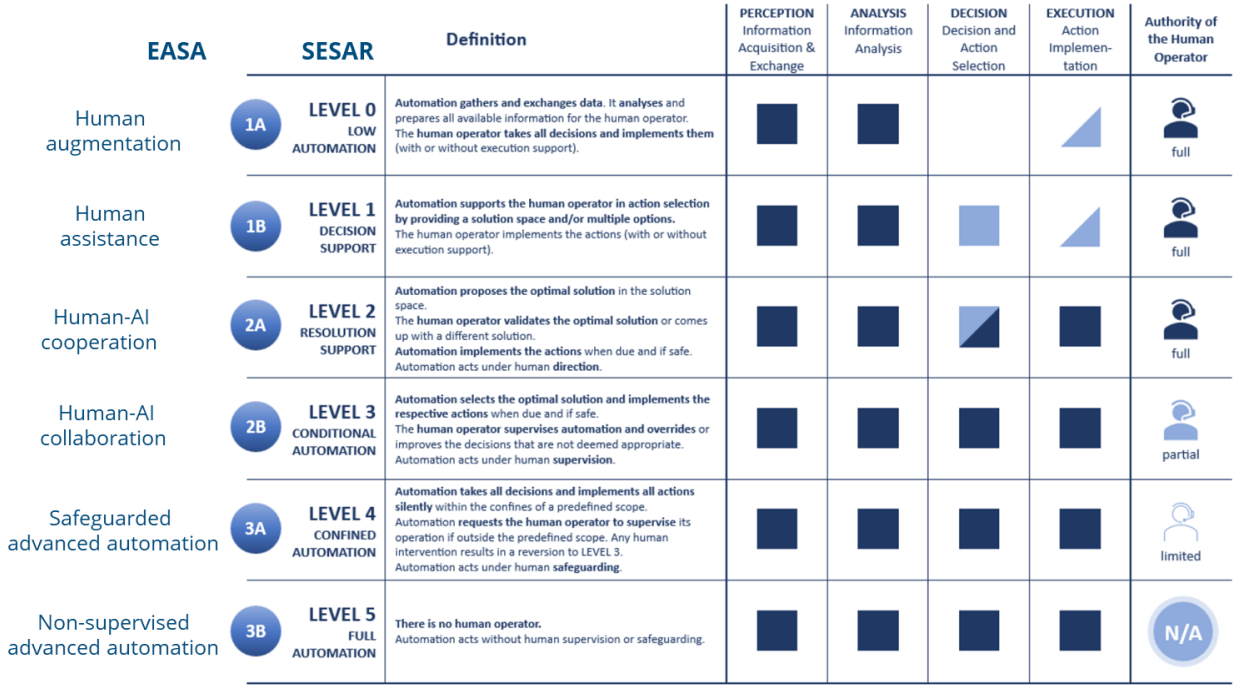

Figure 17. LOAT proposed by SESAR JU and correspondence to EASA AI Levels, adapted from [7].

4.2 Results

This section reports the results of the level-of-automation assessment of each case study.

4.2.1 Case Study 1

Table 5 reports the reference functions of the case study. Table 6 and Figure 18 report the results of the local LOAT assessment (SESAR level).

Table 5. Reference functions of case study 1.

Id.	Name	Description
F1.1	Sector collapsing/decollapsing simulation	To simulate a given sector collapsing/decollapsing configuration in ATM by means of ABMS with the following agents: ECs and PCs across multiple sectors; CWPs; aircraft; FCs.
F1.2	Sector collapsing/decollapsing optimisation	To compute the collapsing/decollapsing configuration in ATM (PC/EC allocation) by means of AES for optimising controller workload in terms of total number and standard deviation of: EC communication to FC; EC separation actions; PC separation actions.

Table 6. Local LOAT assessment of case study 1.

Id.	Name	LOAT	Justification
F1.1	Sector collapsing/decollapsing simulation	0	The automation gathers and analyses data about sector traffic, processing them for simulation. This function does not imply any decision/action selection.
F1.2	Sector collapsing/decollapsing optimisation	1 or 2	The automation computes the optimal solution (i.e., the optimal sector configuration) and proposes such configuration to the human operator (level 2). The human operator implements the action related to sector configuration (level 1).

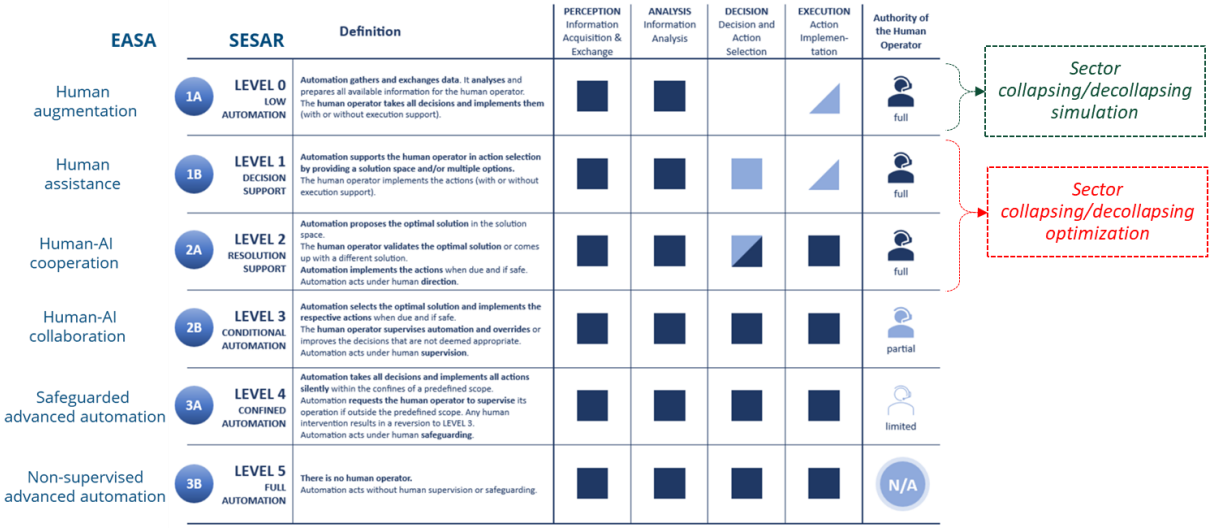

Figure 18. Local LOAT assessment of case study 1.

4.2.2 Case Study 2

Table 7 reports the reference functions of the case study. Table 8 and Figure 19 report the results of the local LOAT assessment (SESAR level).

Table 7. Reference functions of case study 2.

Id.	Name	Description
F2.1	Conflict detection	To detect conflicts between all possible pairs of aircraft.
F2.2	Sequencing and scheduling Optimisation	To sequence and schedule aircraft arrival by minimising the times of arrival.
F2.3	Conflict resolution	To compute conflict resolution actions for separating aircraft by reducing speed and/or holding altitude.

Table 8. Local LOAT assessment of case study 2.

Id.	Name	LOAT	Justification
F2.1	**Conflict detection**	**0 or 3 or 4**	Different assessments are possible, based on the interpretations of the key capabilities for LOAT within the scope of the function. See table Table 9.
F2.2	**Sequencing and scheduling optimisation**	**1 or 2**	The automation computes the optimal solution (i.e., the optimal sequencing and scheduling) and proposes such a solution to the human operator (level 2). The human operator implements the action related to the sequencing and scheduling (level 1).
F2.3	**Conflict resolution**	**1 or 2**	The automation computes the optimal solution (i.e., the conflict resolution actions) and proposes such configuration to the human operator (level 2). The human operator implements the action related to the conflict resolution (level 1).

For the LOAT assessment of the function F2.1, different interpretations are possible, based on the meaning of the terms *Analysis*, *Decision and Action Selection*, and *Execution* of the LOAT taxonomy with respect to the scope of the function F2.1, that is to trigger an alert in case of conflict. In detail, different perspectives may be applied according to the mapping of the LOAT taxonomy with respect to the features of F2.1. The possible perspectives are illustrated in Table 9.

Table 9. Perspectives for the LOAT assessment of the function F2.1.

Persp.	*Analysis*	*Decision and Action Selection*		*Execution*		LOAT
		Human	Machine	Human	Machine	
1	Process the data for alert (conflict detection)	None	Decide that a conflict is occurring. Act to trigger an alert or not.	None	Perform the selected action (alert or not alert)	**3 or 4**
2	Process the data for alerting (conflict detection) and classify the current conflict condition	None	None	Consider the alert	None	**0**
3	Process the data for alerting (conflict detection) and classify the current conflict condition	None	Trigger an alert or not, and select the type of conflict in case of alert	None	In case of conflict, send a (digital) alert to other connected tools (e.g., possible conflict resolution)	**3 or 4**

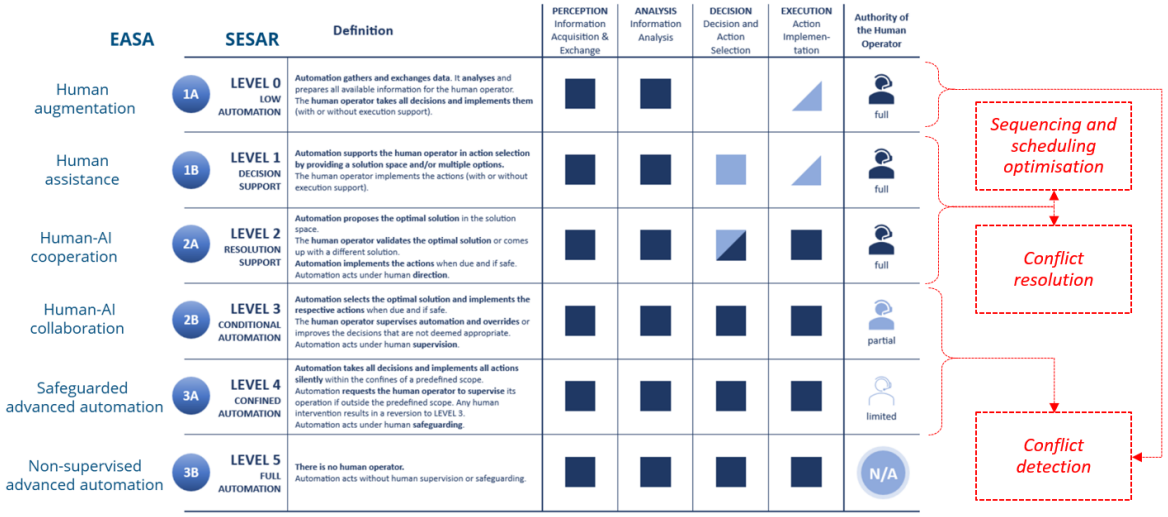

Figure 19. Local LOAT assessment of case study 2.

4.2.3 Case Study 3

Table 10 reports the reference functions of the case study. Table 11 and Figure 20 report the results of the local LOAT assessment (SESAR level).

Table 10. Reference functions of case study 3.

Id.	Name	Description
F3.1	**Data collection and processing**	To identify the current traffic condition, by analysing both internal and external data sources.
F3.2	**Pattern recognition and prediction**	To recognise and predict future airspace congestion.
F3.3	**Real-time decision support and adaptation**	To provide the human operator with the recommendation for the optimal reconfiguration, based on: scenario model, its simulation, real-time updates, historical data for the impact prediction of the proposed solution

Table 11. Local LOAT assessment of case study 3.

Id.	Name	LOAT	Justification
F3.1	**Data collection and processing**	**0**	The automation gathers and analyses traffic data (both internal and external), processing them for identifying the current traffic condition. The automation gathers and analyses traffic data (both manned and unmanned) and other information (Table 3), processing them for identifying the current traffic condition
F3.2	**Pattern recognition and prediction**	**0 or 3 or 4**	Different assessments are possible, based on the interpretations of the key capabilities for LOAT within the scope of the function. See table Table 12.
F3.3	**Real-time decision support and adaptation**	**1 or 2**	The automation computes the optimal solution (i.e., the optimal reconfiguration) and proposes such configuration to the human operator (level 2). The human operator implements the action related to the reconfiguration (level 1).

For the LOAT assessment of the function F3.2, different interpretations are possible, based on the meaning of the terms *Analysis*, *Decision and Action Selection*, and *Execution* of the LOAT taxonomy with respect to the scope of the function F3.2, that is to trigger an alert in case of pattern recognition/prediction of an airspace congestion. In detail, different perspectives may be applied according to the mapping of the LOAT taxonomy with respect to the features of F3.2. The possible perspectives are illustrated in Table 12.

Table 12. Perspectives for the LOAT assessment of the function F3.2.

Persp.	*Analysis*	*Decision and Action Selection*		*Execution*		LOAT
		Human	Machine	Human	Machine	
1	Process the data for alert (pattern recognition for airspace congestion)	None	Decide that an airspace congestion is going to occur in case of DAR. Act to trigger an alert or not.	None	Perform the selected action (alert or not alert)	**3 or 4**
2	Process the data for alerting (pattern recognition for airspace congestion) and classify the future airspace congestion	None	None	Consider the alert	None	**0**

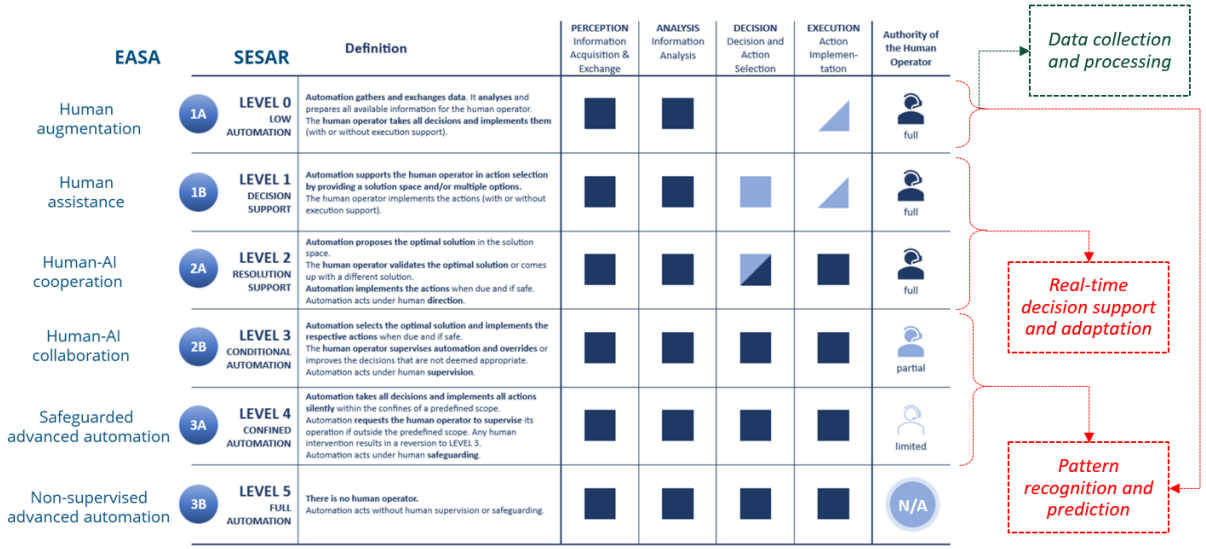

Figure 20. Local LOAT assessment of case study 3.

4.2.4 Case Study 4

Table 13 reports the reference functions of the case study. Table 14 and Figure 21 report the results of the local LOAT assessment (SESAR level).

Table 13. Reference functions of case study 4.

Id.	Name	Description
F4.1	**ARGOS operating in decision support tool mode**	To propose the ATCO the best plan for the traffic in the sector
F4.2	**ARGOS operating in hybrid mode**	To jointly manage the traffic in the sector between ARGOS and ATCOs, by also supporting the hand over of the traffic between them
F4.3	**ARGOS operating in automated mode**	To allow ARGOS to autonomously manage the traffic, requiring the intervention of the human operator when needed

Table 14. Local LOAT assessment of case study 4.

Id.	Name	LOAT	Justification
F4.1	ARGOS operating in decision support tool mode	1	Automation supports the human operator in action section by providing a solution space and/or multiple options. The human operator implements the actions.
F4.2	ARGOS operating in hybrid mode	3	Automation selects the optimal solution and implements the respective actions when due and if safe. The human operator supervises automation and overrides or improves the decisions that are not deemed appropriate. Automation acts under human supervision.
F4.3	ARGOS operating in automated mode	4	Automation takes all decisions and implements all actions within the confines of a predefined scope. Automation requests the human operator to supervise its operations if outside the predefined scope. Automation acts under human safeguarding.

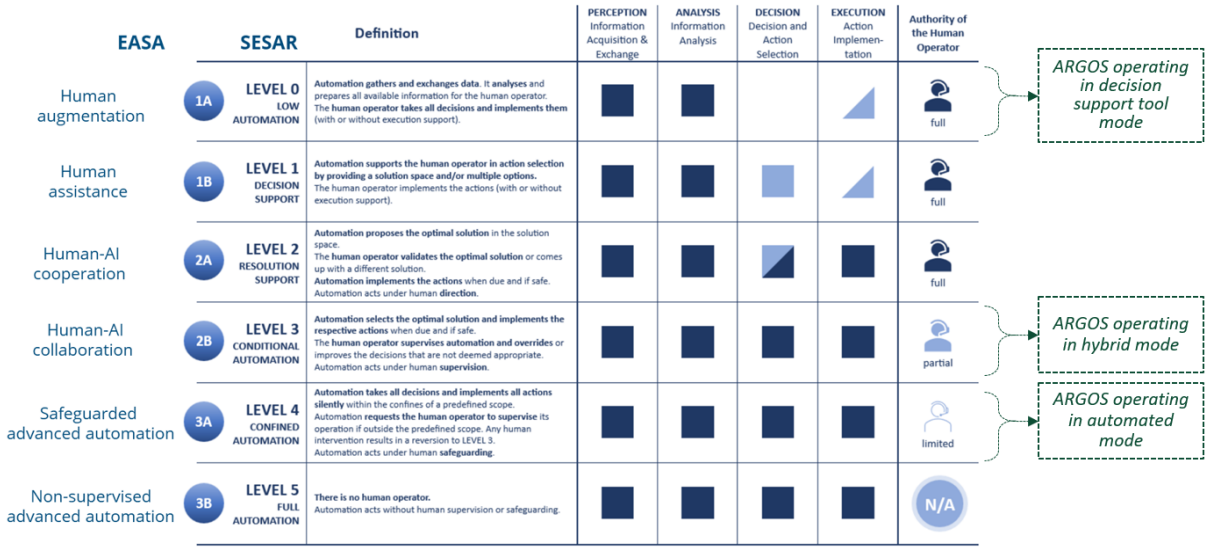

Figure 21. Local LOAT assessment of case study 4.

4.3 Concluding Remarks

While no uncertainties are currently envisaged in case study 4, some issues are present in the LOAT assessments of case studies 1, 2 and 3. Thus, these assessments provide some preliminary arguments to highlight potential **general LOAT gaps/challenges**, or **classes of LOAT gaps/challenges**, within the current LOAT classification of novel systems based on advanced automation. Such arguments are summarised in Table 15, which provides:

- the name of the general gap/challenge;

- the detailed description;
- the traceability to the HUCAN case studies and related functions where the general gap/challenge has occurred.

Table 15. General LOAT gaps/challenges (preliminary).

Id.	Name	Description	Case Study – Function
1	**Ambiguity in LOAT (1 or 2) for automated decision support**	This ambiguity occurs for the LOAT assessment of functions performing automated decision support to human operator, in the case of: (1) automated resolution of optimization problems; (2) human selection and implementation of the action. Indeed, the following conditions are present for this ambiguity: (i). In such functionalities, the automation computes a solution of the reference problem, which is usually stated as an optimization problem. In this respect, the LOAT is 2 since the automation "proposes the optimal solution in the solution space". (ii). However, the action selection and implementation is carried out by the human operator. In this respect, the LOAT is 1 since "the human operator implements the actions (with or without execution support)".	- Case study **1 – F1.2** - Case study **2 – F2.2, F2.3** - Case study **3 – F3.3**
2	**Ambiguity in LOAT (0 or 3 or 4) for automated detection / recognition / prediction**	This ambiguity occurs for the LOAT assessment of functions performing computation for automated detection, recognition, or prediction, with different interpretations for the capabilities "Analysis, Decision and Action Selection" and "Execution" of the LOAT taxonomy. According to such interpretations, several mappings between the scope of the functions and the LOAT capabilities are possible, with different task allocations to the human operator and the machine.	- Case study **2 – F2.1** - Case study **3 – F3.2**

Based on Table 15, the proposed HUCAN case studies will be further used to characterise these gaps/challenges and to study their resolution within the HUCAN project.

5 Liability Analysis

This chapter describes a preliminary assessment of the liability profiles that may be linked or derive from the 4 case studies analysed in the previous chapters.

The scope of the chapter is to introduce and summarise those elements that, in case of practical implementation of the 4 case studies, may determine consequences or – more generally – may be relevant from the liabilities of the entities involved in the future application of the described cases.

In particular, this chapter:

1. uses a preliminary methodology, proposing a structure for the future development of a detailed liability analysis of the 4 case studies that will then be performed under task T4.4;
2. summarises preliminary considerations derived from the analysis of the results of the 4 case studies above.

In order to fully perceive the rationale behind this preliminary liability assessment, it should be considered that, in general, elements relevant for a liability analysis of new applications are linked to the management and mitigation of the risks arising from the said applications and are based on their assessed functioning [(5)] and on the responsibilities of the subjects involved. In particular, liabilities arise when regulatory provisions at any level (EU, national legislations, etc.) and with various binding nature (regulation, guidelines, soft law acts, etc) mandate to a subject/entity the responsibility for the management/implementation/design etc. of a certain application and/or the good performance of the related tasks, and when the same regulatory provisions allocate to the responsible entities liabilities in case the applications implemented and/or the tasks performed are the direct cause of any harmful event determining damages to third parties.

These elements are briefly summarised in the sections below, with focus on the elements of each case study, the human factors assessed, the level of automation attributed and the subjects/entities involved, evaluating if and how these elements may be relevant from the liabilities point of view.

5.1 Case Study 1

5.1.1 Summary of Relevant Elements for Liability Analysis

The analysis of case study 1 - Dynamic Airspace Sectoring revealed key elements that may be relevant for the liability analysis.

System complexity and socio-technical nature: ATM systems are large-scale STS, involving intricate interactions between humans, technology and the environment. Any impact introduced by the implementation of the case study to such systems may have social and technical implications, which

[(5)] The functioning of certain applications, as well as their scope, the domain in which they are implemented, and any other elements capable of impacting their technological development and use, determine the level of risks related to the use of the applications themselves.

should be fully assessed before implementation in order to avoid the arising of new risks and potential sources of liabilities.

Human factors: a common issue in ATM systems' evolution is the discrepancy between the simulated performance evaluations and the real-life outcomes of the operations, based on external human factors. The new approach introduced by the case study includes a specific evaluation of human behaviours that may be critical for the liabilities analysis and for the management of risks, given that human factors can significantly impact the safety and efficiency of the system consequently influencing the risk level of the operations managed by the new system.

New ATM solutions design approach: the proposed approach uses an ABMS and an AES to explore and optimise new ATM configurations. This methodology aims at predicting and enhancing system performance by simulating strategic and pre-tactical scenarios. In the evaluation of elements that could be relevant for the liabilities that may arise in the case study implementation, the reliability of these simulated scenarios must be carefully assessed, as the feasibility of the scenarios in ways other than those estimated could lead to risks to the safety and security of operations and, consequently, could lead to liabilities of the subjects involved should these scenarios not be correctly estimated.

Sector Configuration Optimization: the case study specifically addresses the design and optimization of sector configurations to manage controller workloads effectively. This involves automated tuning of sector settings to ensure optimal workload distribution between ECs and PCs, enhancing overall system performance and safety. Again, the level of automation of these mechanisms and any risks in the event of malfunctioning must be assessed in order to minimise the potential impacts they might have in relation to individual liability.

For the liability analysis, it is therefore crucial to consider how the innovations that the case study introduces might impact the system safety, especially with regard to human factors, the reliability of simulations and the real-world applicability of optimised solutions. Any gaps or failures in assessing these aspects could potentially lead to system failures, accidents or other incidents, making the thorough evaluation of these elements vital in the decision-making process.

5.1.2 Preliminary List of Elements Emerged from the Human Factor Analysis

The human factors analysis of case study 1 Dynamic Airspace Sectoring reveals several elements that may have consequences relevant for a liability analysis.

In the implementation of the case study, there is a minimal impact on the role and responsibilities of the OPS Supervisor – Flow Manager, specifically in reviewing workload forecasts alongside sector optimization results. Key tools also experience changes, particularly in the HMI, which may display ATCOs workload forecasts. This, while the communication and organisation aspects of the OPS Supervisor – Flow Manager's role are not impacted.

These impacts suggest that while the case study introduces enhancements, it does not fundamentally alter the human operations nor does it introduce significant new risks. Nonetheless, even minor changes in tools and tasks require careful evaluation to ensure that they do not inadvertently introduce risks of errors or reduce the overall system reliability, which could have liability implications if they lead to risks of operational failures, inefficiencies or safety issues.

5.1.3 Preliminary List of Elements Derived from the Level of Automation Analysis

Points of attention in the level of automation assessment for case study 1 Dynamic Airspace Sectoring, that may produce or determine consequences relevant for the liability analysis, relate to:

Data Gathering and Analysis Automation (Level 0): the automation level is limited to data collection and analysis, without engaging in decision-making. This low level of automation leaves more space for the human interpretation of data and decisions making, as the automation provides no decision support, potentially leading to human errors in configurations and therefore risks that may be sources of future liabilities for the entities involved.

Optimization Automation (Levels 1 or 2): the automation suggests optimal sector configurations (Level 2), but the final decision and implementation are left to the human operator (Level 1). This creates a reliance on human judgement to accept or adjust the proposed configurations. As above, there is space for human operators to misinterpret or override automated suggestions, leading to inappropriate sector configurations. The dual level of automation (1 and 2) may cause confusion regarding the role and extent of automation, possibly resulting in accountability issues if an error occurs and consequently in the realisations of risks that may be sources of subsequent liabilities.

5.1.4 Preliminary Identification of Potentially Liable Subjects and/or Entities

In case study 1 Dynamic Airspace Sectoring, several entities and individuals could potentially be held liable for malfunctions, errors, or harmful events arising from the use of the technology.

Firstly, the developers and vendors of the automation systems, including those responsible for the algorithms used in sector collapsing/decollapsing simulations and optimizations, have a fundamental duty to ensure that their systems are safe, reliable and accurately reflect real-world scenarios. Any deficiencies in the software's design, implementation, or updates that lead to incorrect data analysis or suboptimal sector configurations could place cases of product liability on these subjects in case of damages.

Secondly, the OPS Supervisor – Flow Manager, responsible for interpreting and acting on the automation’s recommendations, could be liable if their decisions based on these outputs potentially result in errors or safety issues. This includes ensuring that they adequately understand the system's outputs and limitations and that they do not override automation suggestions without just cause or sufficient understanding.

Regulatory authorities and oversight bodies also bear significant responsibilities. They are tasked with certifying the safety and efficacy of ATM technologies and ensuring that these systems meet required standards. If these bodies fail to establish clear safety guidelines, approve inadequate systems, or neglect to enforce proper operational protocols and training for human operators, they could be considered liable for any resulting adverse events.

Lastly, the organisations operating the ATM systems, such as ATCPs, share responsibilities for providing comprehensive training for their personnel, maintaining up-to-date systems, and establishing clear procedures for integrating automation into their workflows. If organisational failures contribute to mishandling or misinterpretation of automation outputs, these entities could be held liable in case of damages.

5.2 Case Study 2

5.2.1 Summary of Relevant Elements for Liability Analysis

The analysis of case study 2 AI-Powered Digital Assistant in TMA revealed key elements that may be relevant for the liability analysis.

AI and automation role: the digital assistant referred to in the case study supports ATCOs by providing suggestions for aircraft sequencing and conflict resolution. It uses RL to suggest waypoints, speed adjustments and altitude holdings to ensure safety, optimise landing times, and enhance runway throughput. The automation operates on different levels: SSL focuses on aircraft sequencing, while the CML addresses potential conflicts. The well functioning of these components is crucial for the minimisation of risks that can in turn interfere with the good functioning of the applications and consequently lead to potential liabilities.

Human-AI interaction: in case study 2 the interaction between AI recommendations and human decision making may raise issue interpretation and reliance on AI-generated suggestions, which could impact safety and operational efficiency.

Training and robustness: the RL model is trained using historical and simulated data provided by ENAV, focusing on high-complexity scenarios. The system's ability to generalise to new, unseen scenarios and avoid unintended consequences, such as negative side effects or reward hacking, is critical for safety and reliability and, consequently, for the introduction and management of risks.

5.2.2 Preliminary List of Elements Emerged from the Human Factor Analysis

The human factors analysis of AI-Powered Digital Assistant in the TMA reveals several elements that may have consequences relevant for a liability analysis.

The AI-Powered Digital Assistant in the TMA significantly impacts the tools available to PCs and ECs, introducing advanced functionalities for conflict detection and resolution. While the DA aims to enhance the controllers' perception and decision-making, it also imposes additional tasks, such as verifying the DA's suggestions and integrating them into the overall traffic management strategy.

This shift could affect controllers' workload and their reliance on technology that may raise concerns about over-reliance on automation and potential complacency. The requirement for controllers to assess and validate AI-generated conflict resolutions adds a layer of responsibility, where errors in judgement could have safety repercussions, potentially leading to liability if mishandling of suggestions results in incidents. Furthermore, the development and deployment of the DA, along with its human-machine interface, places responsibility on the developers to ensure the system's accuracy.

Any deficiencies in these areas, such as flawed conflict detection algorithms or user interface issues that could lead to misinterpretation of data, may result in operational errors and, consequently, in liabilities of both the technology developers and the ATCOs, depending on the root cause of any failures or incidents.

5.2.3 Preliminary List of Elements Derived from the Level of Automation Analysis

Points of attention in the level of automation assessment for case study 2 AI-Powered Digital Assistant in the TMA, that may produce or determine consequences relevant for the liability analysis, relate to:

Conflict detection (Level 0, 3, or 4): the level of automation for conflict detection varies significantly, ranging from minimal automation (Level 0) to more advanced levels, where AI plays a crucial role in identifying potential conflicts. The variety in automation levels may have different impacts on the system capabilities or in the interpretation of those capabilities. This variability may lead to uncertainty about the extent of reliance on automated systems versus human judgement, potentially resulting in delayed responses or incorrect conflict detection. The liability concerns in this scenario may revolve around determining responsibility when a conflict is either not detected or improperly communicated, especially if the system is expected to function at a higher level of automation.

Sequencing and scheduling optimization (Level 1 or 2): the automation level suggests optimal sequencing and scheduling solutions, but final decision-making and execution rest with human operators. This approach, where automation supports but does not supplant human decision-making, may create ambiguity about accountability, particularly if a proposed automated solution is incorrect or not implemented properly. In cases where miscommunication or misinterpretation of automated suggestions leads to operational errors, there could be disputes over whether the fault lies with the human operators or the system developers.

Conflict resolution (Level 1 or 2): similar to sequencing and scheduling optimisation, the automated conflict resolution mechanism provides suggestions that human operators must evaluate and execute. The reliance on human oversight implies that errors can occur, if controllers misunderstand or overlook suggestions from the AI system. The potential for liability may arise from the shared responsibility for safety-critical decisions, since errors in judgement or execution could be attributed to either a failure of the system to provide adequate guidance or to the failure of the operator to correctly interpret and act on that guidance.

5.2.4 Preliminary Identification of Potentially Liable Subjects and/or Entities

In case study 2 AI-Powered Digital Assistant in TMA, several entities could be considered potentially liable in the event of malfunctions, errors, or harmful events caused by the use of the implementation of the case.

Firstly, the developers and designers of the AI system, including the software engineers and data scientists responsible for the AI algorithms and the overall system architecture, hold significant responsibility. They are accountable for ensuring the system's accuracy, reliability, and robustness, particularly in safety-critical applications like air traffic control (product liability).

Secondly, the ANSPs bear responsibility for integrating the system into operational environments, including ensuring that controllers are adequately trained and that the system functions correctly within existing operational protocols. At the same level, regulatory authorities overseeing ATM systems may also share liability if there are lapses in the certification or oversight of the technology's deployment. In case of any incident, liability could potentially be distributed among these entities depending on where failures occurred, whether in system design, implementation, operation, or oversight.

Furthermore, manufacturers and suppliers of hardware components, including sensors and communication systems integral to the AI-Powered Digital Assistant's operation, could also be held liable if technical malfunctions or defects contribute to an incident. In addition, the developer of the reinforcement learning models used for conflict resolution has the specific responsibility to ensure these models are thoroughly tested and validated, including under rare or unexpected conditions that might occur in real-world scenarios.

Another critical aspect is the role of system integrators, who ensure that the AI assistant is seamlessly integrated with existing air traffic control systems and interfaces. Any errors in integration, such as incompatible interfaces or data misinterpretation, could also lead to liability issues.

Lastly, the operators themselves – specifically the ATCOs using the system – may have some degree of liability if human error, such as misinterpretation of the AI's recommendations or failure to act on alerts, contributes to an incident. However, risks and related liabilities may be mitigated or excluded by the extent of training provided by the ANSP and the clarity of the system's user interface and instructions. For example, risks may be mitigated with specific training to the responsible parties and liabilities may be excluded and/or avoided – whenever there is proof of compliance with the regulations mandating the training (e.g. by proving that training sessions have been actually performed). If not excluded and/or avoided, with the same proof liabilities can also be mitigated in their extent (e.g. in the amount of compensation to be provided to the damaged party). This on the assumption that the cause of damage can be directly identified in the lack or insufficient training.

5.3 Case Study 3

5.3.1 Summary of Relevant Elements for Liability Analysis

The analysis of case study 3 Dynamic Airspace Reconfiguration (DAR) Service for U-Space revealed key elements that may be relevant for the liability analysis.

Roles and responsibilities: the DARM is responsible for initiating and managing airspace reconfigurations, while USSPs manage communication and compliance for UAS operators. The CISP ensures information integrity and dissemination, and ATS and ATCOs manage airspace design and traffic coordination. Liabilities could arise if any party fails to perform these roles effectively, leading to safety issues or operational disruptions.

Information exchange: the DAR process heavily relies on accurate and timely information exchange among ATM and U-Space systems. Failures or inaccuracies in information provided by CISP, or communication lapses by USSPs, could result in improper airspace reconfiguration, leading to the occurrence of potential risks and liabilities.

System integration and performance: the seamless functioning of DAR involves integration of multiple systems and services, including mandatory U-space services (e.g., UAS flight authorization, geo-awareness) and advanced services (e.g., strategic deconfliction). Malfunctions or design flaws in these systems could affect their performance, contributing to risks of damages, safety hazards and related liabilities.

Compliance and monitoring: the case study implies the strict adherence to airspace restrictions and operational compliance by UAS operators, pilots and other stakeholders. Failure to ensure compliance

or monitor deviations effectively may result in liabilities for any incidents caused, for example, by unauthorised UAS operations within restricted airspace.

Dynamic decision-making: the DAR service involves real-time decision-making and adjustments based on evolving traffic patterns. Any gaps in the decision making process, whether by the DARM or ATCOs, may result in unsafe conditions or airspace management failures, impacting liability.

Overall, liability analysis in this case study should consider the effectiveness of stakeholder coordination, the reliability of information exchange systems, the performance of integrated services, and adherence to compliance requirements. Each element contributes to the overall safety and effectiveness of the DAR service and any gap could determine liability implications.

5.3.2 Preliminary List of Elements Emerged from the Human Factor Analysis

The human factor analysis of case study 3 DAR Service for U-Space reveals several elements that may have consequences relevant for a liability analysis.

The role of the DARM is clearly impacted by the automation tool, which alters the dynamics of how airspace reconfiguration decisions are made. The introduction of the tool adds a layer of complexity in the DARM's core responsibilities. In the case study implementation phase, the DARM should actively engage with the tool's outputs, including reviewing and validating the proposed airspace modifications.

This responsibility increases the potential for errors or oversight, particularly if the tool provides inaccurate or inadequate recommendations. The high impact on key tools underscores the tool's central role in analysing data and modelling scenarios for DAR requests, thereby elevating the importance of its reliability and accuracy. Any malfunction or incorrect output from the tool could directly lead to improper airspace configurations, potentially causing safety issues and operational disruptions.

The tool's minimal impact on communication indicates that the primary communication changes involve transmitting selected solutions to the CIS, which then disseminates this information to relevant stakeholders. However, even minor failures in this communication process could result in significant operational issues if updated airspace restrictions are not properly conveyed to UAS operators and pilots.

Lastly, the fact that organisation and planning are not directly impacted by the tool suggests that while the procedural aspects remain stable, the integration of advanced tools necessitates a rigorous validation process. This validation is crucial for ensuring that the tool's recommendations are accurately reflected in the airspace configuration. The reliance on advanced automation tools extends the need for precise oversight and effective error management, as any failure or misuse could lead to considerable safety risks and operational inefficiencies, thereby affecting liability in the event of malfunctions or harmful events.

This may happen whenever a regulatory provision on validation and oversight procedures specifically allocates liabilities to the responsible entity/subject in the event of harmful events causing damages and, consequently, when it is proven that damages were directly caused by a malfunctions determined by a gap or inefficiency during the said validations/oversight procedures and/or by non-compliance with the related regulations.

5.3.3 Preliminary List of Elements Derived from the Level of Automation Analysis

Points of attention in the level of automation assessment for case study 3 DAR Service for U-Space, that may produce or determine consequences relevant for the liability analysis, relate to:

Data collection and processing (Level of Automation 0): this function involves the gathering and analysis of traffic data to identify current traffic conditions. The automation level of this function is limited to data collection and processing, without automated pattern recognition or predictive capabilities. This may potentially impact the identification of emerging traffic patterns, which could influence timely decision-making and may affect liability, if delayed responses lead to operational issues.

Pattern recognition and prediction (Levels of Automation 0, 3, or 4): the assessment of this function reveals a variety of automation levels. Depending on the perspective, pattern recognition and prediction could either remain at a low level of automation (0), where the system merely processes data without advanced predictive capabilities, or achieve higher levels of automation (3 or 4) where the system autonomously recognizes patterns and predicts airspace congestion. This variability may lead to discrepancies in the system's capability to preemptively address potential issues and may affect liabilities if inadequate pattern recognition leads to unaddressed congestion or safety hazards.

Real-time decision support and adaptation (Levels of Automation 1 or 2): the automation provides decision support by computing and proposing optimal reconfigurations to the human operator. However, the final decision and implementation of the reconfiguration are performed by the human operator (Level 1). The differences in the transition from the automation-supported decision-making (Level 2) to the human execution (Level 1) may create variations in how quickly and effectively reconfigurations are implemented, potentially impacting operational safety and efficiency, and influencing liability if delays or errors occur during manual implementation.

5.3.4 Preliminary Identification of Potentially Liable Subjects and/or Entities

In case study 3 DAR Service for U-Space, several entities could be considered potentially liable in the event of malfunctions, errors, or harmful events caused by the use of the implementation of the case.

The DARM holds primary responsibility for overseeing the DAR process. As the role involves real-time monitoring and decision-making based on complex data, any oversight, incorrect decision-making or failure to implement the reconfiguration promptly could lead to liability, particularly if it results in unsafe conditions or traffic conflicts.

The USSPs are responsible for facilitating UAS flight authorizations, communicating airspace restrictions, and ensuring compliance with DAR adjustments. Gaps in these functions, such as miscommunication of airspace restrictions or failure to enforce compliance, could contribute to operational hazards and subsequent liability.

The CISP, which maintains and distributes airspace data, also plays a critical role. Any inaccuracies or delays in data dissemination by the CISP could lead to incorrect situational awareness, potentially causing collisions or other incidents, therefore impacting its potential liability.

The ATCOs, tasked with managing manned aircraft and coordinating with the DARM, could be held liable if their coordination fails to address UAS traffic effectively or if they do not ensure that airspace reconfigurations are properly communicated and enacted.

Finally, the automation tools used within the DAR system could also introduce liability if their recommendations or reconfigurations lead to errors. These tools, while designed to support decision-making, rely on accurate data and correct implementation; any failure in the automation's accuracy or integration could have significant consequences. Liability could be further complicated by the interplay between human and automated decision-making, highlighting the need for clear accountability and robust oversight mechanisms to manage and mitigate risks associated with DAR services.

5.4 Case Study 4

5.4.1 Summary of Relevant Elements for Liability Analysis

The analysis of case study 4 Dynamic Allocation of Traffic between ATCO and System implied the evaluation of the ATC Real Ground-breaking Operational System (ARGOS), which revealed key elements that may be relevant for the liability analysis.

Automation levels and modes: ARGOS operates in three distinct modes - Decision Support Tool (L3), Hybrid (L5), and Automated (L8) - each with varying degrees of automation and human intervention. These differences can have an impact in the human-automation interaction that can in turn hold significant consequences for the liabilities allocation in case of malfunctioning and errors.

System checks and fail-safes: the ARGOS-Checker (CARGOS) is an independent subsystem that validates ARGOS's proposed plans and ensures that the overall situation remains manageable. This dual-check system adds a layer of safety but introduces at the same time complexities that shall be carefully taken into account in ensuring the performance.

Operational transitions: transitions between different modes are controlled by the tactical supervisor and depend on traffic complexity and ARGOS's performance. Issues in transitioning, particularly from fully automated to partially automated modes, could impact safety and may raise liability profiles.

System malfunctions: procedures for deactivating or reverting ARGOS to lower operational modes in case of malfunction, as well as the role of CARGOS in detecting such issues, are crucial. The system's ability to handle or mitigate errors, and the protocols for addressing failures, are crucial to mitigate risks of malfunctions and to consequently mitigate/avoid the raising of related liabilities.

In this case, as in the other examples of emerging liabilities for damages caused by malfunctions/errors, the path to the recognition of possible liabilities requires: i) the existence of rules mandating a particular entity/subject to ensure the reliability of risks mitigation procedures and error/malfunction management protocols; ii) the attribution, by the same rules, of the responsibility for the proper functioning of these systems to certain entities/subjects; iii) the allocation of liabilities, in the event of proof that damages were directly caused by the said errors and malfunctions, to the responsible entities. Again, risks of damages caused by errors/malfunctions and the emergence of the associated liabilities of the responsible parties can be mitigated/excluded by demonstrating the accuracy and compliance of the prescribed procedures with the regulations imposing them.

5.4.2 Preliminary List of Elements Emerged from the Human Factor Analysis

The human factor analysis of the ARGOS case study reveals several elements that may have consequences relevant for a liability analysis.

Tool integration and management: on one hand, RSUPs will use additional new tools and dashboards for monitoring and managing ARGOS, increasing complexity in tool usage and coordination. Inefficiencies or errors in using these tools could impact system performance and operational safety; on the other hand, ATCOs will interact with different tools based on the operational mode, which may increase the risk of errors if they are not adequately trained or if tools do not integrate seamlessly with existing systems.

Communication changes: the introduction of ARGOS may alter communication protocols between RSUPs, ATCOs, and other roles. Miscommunication or delays in communication could result in misunderstandings or operational errors, raising liability concerns.

Dynamic operational scenarios: the ability to switch between different operational modes during a shift introduces complexity. Mismanagement of these transitions or failure to properly configure the system for the current mode could affect system performance and safety.

5.4.3 Preliminary List of Elements Derived from the Level of Automation Analysis

In the ARGOS case, the levels of automation range from decision support (Level 1), hybrid mode (Level 3), to full automation (Level 4). Each level carries specific elements that could influence liability analysis.

At Level 1, where automation provides recommendations without implementation authority, the human operators maintain primary responsibility, suggesting that liability would likely rest with the human controller in case of errors.

At Level 3, the hybrid mode introduces shared management of traffic, where both the system and human operators have roles in decision-making and execution. This shared responsibility could complicate liability determination, particularly if there is ambiguity in the division of roles and tasks.

At Level 4, the system operates autonomously, taking all decisions within a defined scope but requiring human intervention when limits are exceeded.

This high level of automation implies that liability might shift more towards the system designers and operators, especially if failures occur due to system errors or inadequate safeguards.

The transition mechanisms between these modes also present potential liability challenges, as they require clear protocols and timely human intervention, failure of which could lead to safety incidents. These elements highlight the need for a robust framework to clarify accountability across different levels of automation.

5.4.4 Preliminary Identification of Potentially Liable Subjects and/or Entities

In the ARGOS case, several parties could be identified as accountable and therefore liable in case of malfunctions, errors, or any resulting harmful events. First of all, EUROCONTROL MUAC bears

significant liability for the system's overall reliability and safety. This includes the software's design, the integration of subsystems like the CARGOS and the implementation of safeguards and fail-safes.

The TS and ATCOs who oversee the operation of ARGOS play crucial roles in its functioning. They are responsible for managing transitions between the different system levels (L3, L5, L8), monitoring system performance, and intervening when necessary. Failures in these areas, such as inadequate response to system alerts or improper management of mode transitions, could lead to safety breaches and thus liability.

The developers of CARGOS, which independently verifies the plans proposed by ARGOS, are also accountable, particularly if this subsystem fails to detect and correct errors, leading to unsafe conditions. Moreover, the training organisations tasked with preparing ATCOs and supervisors to use ARGOS and manage its various automation levels are liable for ensuring that personnel are sufficiently skilled and knowledgeable. Inadequate training that results in operational mishandling or failure to intervene could implicate these entities.

In conclusion, liability in the event of ARGOS-related incidents could be shared among the ANSP, the TS and ATCOs responsible for day-to-day operations, the developers of both ARGOS and its subsystems, and the organisations responsible for training the system's operators. This multifaceted liability framework underscores the complexity of attributing responsibility in highly automated systems where both human and technological factors are deeply intertwined.

5.5 Concluding Remarks

This chapter aimed at providing preliminary lists of the elements detected from the analysis of the four case studies that, in case of practical implementation of the 4 case studies, may determine consequences or – more generally – may be relevant from the liabilities standpoint.

In particular, this chapter highlighted those preliminary elements for the future development of a detailed liability analysis to be performed under task T4.4, and summarised preliminary considerations evaluating relevant elements derived from the overall description, scope and functioning, the human factor interactions, the level of automation of each case and roles and responsibilities of each entity involved.

In the subsequent phase of the project, the in depth analysis of the concept introduced in this chapter will be performed, in order to focus on the regulatory context and requirements and other relevant elements that may lead to a clear allocation of the potential liabilities identified above, proposing, when feasible, potential mitigation measures and solutions.

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6 Conclusion

This document presents a detailed description of the case studies being addressed by the HUCAN project. In particular, four case studies have been selected in order to study a holistic and unified approach to certification and to map the challenges that are associated with certification issues. The case studies cover different aspects of the capacity on demand concept, address different kinds of airspaces (i.e., middle airspace, TMA, U-space) and rely on different technologies, including also unsupervised techniques for the optimization in airspace configuration and traffic management (e.g., evolutionary programming and reinforcement learning). The document highlights in particular the level of automation and the human-factor impact of the reference systems. In addition, the document provides a preliminary analysis of the gaps and challenges regarding the assessment of the level of automation and the liability analysis, based on the specification of the case studies.

For the human factors, the analysis has assessed the human-activity impacts brought by each case study. Such impacts are intended as changes with respect to the human aspects in the baseline solution or more generally the current air traffic operations, and are assessed with respect to different human-factor areas: key role, tasks and responsibilities; key tools; communication; organisation and planning. The analysis has shown different levels of impacts, ranging from generally minor impacts (case study 1) to relatively high impacts (case study 4).

For the level of automation, the analysis has applied a functional automation-related approach for each case study, with the identification of the reference functions (i.e., high-level functions related to the advanced automation capabilities) and the evaluation of the "local" automation level to be assigned to each reference function. As Levels of Automation Taxonomy (LOAT), the assessment has employed an adaptation of the LOAT proposed by S3JU. In regard to the assessment results, while no uncertainties are currently envisaged in case study 4, some issues are present in the LOAT assessments of case studies 1, 2 and 3. Thus, these assessments have been exploited to derive some preliminary arguments underlying general LOAT gaps/challenges, or classes of LOAT gaps/challenges, within the current LOAT classification of novel systems based on advanced automation. Such arguments mainly imply ambiguities in LOAT for:

- automated decision support (LOAT 1 or 2);
- automated detection / recognition / prediction (LOAT 0 or 3 or 4).

For the liability analysis, the document summarises: a preliminary methodology, proposing a structure for the future development of a detailed liability analysis of the case studies; preliminary considerations derived from the analysis of the assessment results (both human factor and level of automation) of the case studies. Liability analysis will be finalised in task T4.4.

The following main aspects have emerged from the analysis of the proposed case studies in regard to their potential certification issues:

- **Certification Issue #1 – Human Factors Change Impacts**
  All the case studies introduce highly automated solutions, also with the support of AI technology in some of the reference solutions. The analysis showed that all these highly automated features produce relevant impacts on the human factors aspects. The most

significant impacts were generally assessed for the changes regarding human roles/tasks/responsibilities and key tools.

- **Certification Issue #2 – LOAT Gaps/Challenges**
    - Some issues are present in the LOAT assessments of the proposed case studies and provide some preliminary arguments to highlight potential general gaps/challenges within the current LOAT classification of novel systems based on advanced automation. The encountered issues concern some ambiguities for the LOAT assessment of the following classes of functions:Automated decision support – For this class, an ambiguity occurs in the case of automated resolution of optimization problems and human selection and implementation of the action. The ambiguity is between the assignment of level 1 or 2 for the LOAT of the functions belonging to such class.
    - Automated detection/recognition/prediction – For this class, an ambiguity occurs due to different interpretations for the capabilities “Analysis, Decision and Action Selection” and “Execution” of the LOAT taxonomy. The ambiguity is between the assignment of level 0 or 3 or 4 for the LOAT of the functions belonging to such class.

- **Certification Issue #3 – Potential Liabilities**
  The preliminary liability analysis highlighted some elements that may determine consequences or may be relevant from the liabilities of the entities involved in the future application of the case studies. In detail, several entities and individuals could potentially be held liable for malfunctions, errors, or harmful events arising from the use of the reference technology in all the case studies. Firstly, the automation tools could introduce liability if their outputs lead to errors. Thus, the developers and designers of systems (including the software engineers and data scientists responsible for the AI algorithms, where applicable) hold significant responsibility. But also operators, organisations operating the ATM systems, regulatory authorities and oversight bodies generally bear significant responsibilities for their roles and tasks. For case study 4, a significant liability challenge is present due to the transition mechanisms between the diffent automation modes, as they require clear protocols and timely human intervention, failure of which could lead to safety incidents.

Also, the following aspects have emerged from the analysis of the use cases in the perspective of the certification process:

- **Certification Process Aspect #1 – Operational Usage of Highly Automated Technologies**
  The analysis confirmed that highly automated technologies shall be analysed considering their operational usage. As evident in the proposed use cases, this latter can be different depending on specific choices made at local level. This can imply the need of certifying the specific solutions (i.e., use of a technology), rather than technolgies tout court.
- **Certification Process Aspect #2 – Impact of Highly Automated Technologies**
  The analysis shown that all highly automated technologies pose same kind of considerations and issues. This further confirms that we need a certification process for highly automated technologies, rather than for just AI-based technologies (even if these latter may raise peculiar challenges, such as for instance those related to explainability).
- **Certification Process Aspect #3 – Early Assessment**
  The proposed kind of assessment is worth being anticipated during the design process (i.e., when the solution is at low TRL) in order to be aware of the potential impact of specific human

factors and liability issues on the certification process and consequently define suitable mitigations (which may also include changing the roles and the tasks, of the operators involved or the way they interact with system, and/or changing the level of automation).

The information contained in this document (both detailed specifications and assessments of case studies) will be used to feed and validate the theoretical research, to consolidate the certification issues and the certification process aspects, to design and test the certification method, and to produce and validate guidelines for certification.

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8 List of Acronyms

Table 16. List of acronyms.

Acronym	Description
ABM	Agent-Based Modelling
ABMS	Agent-Based Modelling and Simulation
ACOP	Arrival digital assistant with Conflict Prevention
ADS/B	Automatic Dependent Surveillance – Broadcast
AES	Agent-based Evolutionary Search
AI	Artificial Intelligence
AMAN	Arrival Manager
AMC	Acceptable Means of Compliance
ANSP	Air Navigation Service Provider
ARGOS	ATC Real Ground-breaking Operational System
ASP	Airspace, Systems & Procedures
ASSP	Arrival Sequencing and Scheduling Problem
AT	Air Traffic controller
ATC	Air Traffic Control
ATCO	Air Traffic COntroller
ATM	Air Traffic Management
ATS	Air Traffic Service
AURA	PJ34-W3 AURA – ATM U-Space Interface Project
AUSA	ATM-U-space Shared Airspace
CAP	Capacity Management
CARGOS	Check ARGOS
CDO	Continuous Descent Operations
CDR	Conflict Detection and Resolution
CFL	Cleared Flight Level
CIRA	Centro Italiano Ricerche Aerospaziali
CISP	Common Information Service Provider
CML	Conflict Management Layer
CNS	Communications, Navigation & Surveillance

CO	Current Operations unit
CPA	Closest Point of Approach
CPDLC	Controller Pilot Data Link Communication
CR	Conflict Resolution
CTR	Control Zone
CWP	Controller Working Position
DA	Digital Assistant
DAR	Dynamic Airspace Reconfiguration
DARM	Dynamic Airspace Reconfiguration Manager
DCM	Dynamic Capacity Management
DCT TO	Direct To
DCT TOP	Direct To
DMAN	Departure Manager
DS	Duty Supervisors
DST	Decision Support Tool
DTW	Dynamic Time Warping
EASA	European Union Aviation Safety Agency
EC	Executive Controller
ENAV	Ente Nazionale di Assistenza al Volo
ENSURE	ATM-Uspace Interface and Airspace Reconfiguration Service Project
EOS	Executive Operational Support
ER	Exploratory Research
ETA	Expected Time of Arrival
EU	European Union
EVOAtm	EVOlutionary ATM
FAF	Final Approach Fix
FC	Flight Crew
FDPS	Flight Data Processing System
FM	Flow Management
FRAM	Functional Resonance Analysis Method
GM	Guidance Material
HMI	Human-Machine Interface

HTA	Hierarchical Task Analysis
HUCAN	Holistic Unified Certification Approach for Novel systems based on advanced automation
ICAO	International Civil Aviation Organization
LoA	Letter of Agreement
LOAT	Levels of Automation Taxonomy
LORD	Lateral Obstacle & Resolution Display
LOS	Loss of Separation
MOEA	Multi-Objective Evolutionary Algorithm
MTCD	Medium Term Conflict Detection
MUAC	Maastricht Upper Area Control
NASA	National Aeronautics and Space Administration
NOTAM	NOtice To AirMen
NSGA	Non-dominated Sorting Genetic Algorithm
NUVASC	Nuovo UAV – Volo Autonomo in Scenari Complessi
OPS	Operations
OSED	Operational Services and Environment Definition
PC	Planner Controller
PRO	Planning & Roster Office
QNH	Mean sea level pressure
R&D	Research and Development
REG	REGulation
RL	Reinforcement Learning
RS	Room Supervisor
RSup / RSUP	Room Supervisor
S3JU	SESAR 3 Joint Undertaking
SESAR	Single European Sky ATM Research
SMAN	Surface Manager
SSL	Sequencing and Scheduling Layer
STCA	Short Term Conflict Alert
STS	Socio-Technical System
SWIM	System-Wide Information Management
TactSup	Tactical Supervisor

TCT	Tactical Conflict Detection and Resolution
TFL	Transfer Flight Level
TIS	Traffic Information Service
TMA	Terminal Manoeuvring Area
TOD	Top of Descent
TRL	Technology Readiness Level
UAS	Unmanned Aerial System
USSP	U-Space Service Provider
UTM	Unmanned Traffic Management
VERA	Verification and Resolution Advisory Tool

Appendix A Case Studies Forms

This chapter reports the summary forms of the case studies. The forms are illustrated in sections 0 (case study 1), A.2 (case study 2), A.3 (case study 3), and A.4 (case study 4).

A.1 Case Study 1: Dynamic Airspace Sectoring

Table 17. Form of case study 1.

Case Study 1	Dynamic Airspace Sectoring
Reference Project	
Project Summary	**EVOAtm – EVOlutionary ATM, H2020-SESAR-2016-2** The projects aims to build a framework to better understand and model how architectural and design choices influence the ATM system and its behaviours, and vice versa how the expected ATM overall performances drive the design choices. The EvoATM project modelled a specific part of the ATM system combining agent-based paradigms with evolutionary computing. Specifically, it defined a solver which finds an optimal tuning of the design of new/modified ATM components to accomplish the expected performances. It tested the framework by using known scenarios and quantitative indicators to validate its effectiveness in terms of: change impact assessment, support to design and support to strategic thinking.
Project Timeline	2018 – 2019
References	https://www.sesarju.eu/projects/evoatm https://cordis.europa.eu/project/id/783189
Contacts	Domenico Pascarella (CIRA) – d.pascarella@cira.it
Description	
Purpose	The case study defines an approach to support the design of new ATM solutions, including the evaluation of human behaviour. The approach adopts a combined computational paradigm, which involves Agent-Based Modelling and Simulation (ABMS) to specify and analyse the ATM models, and Agent-based Evolutionary Search (AES) to optimise the design of the new solutions. The purpose is to explore new configurations for the ATM system in advance, namely during the strategic or pre-tactical phases. Such optimisation is intended with respect to the estimated performance of the simulated ATM system and implies the minimisation or maximisation of some reference ATM performance metrics. The case study is applied to the design of sector collapsing/decollapsing configuration to optimise controller workloads. It delivers the automated and optimal tuning of the configuration of elementary sectors in the collapsed sectors in order to optimise controller workload, for both Executive Controllers (ECs) and Planner Controllers (PCs).
High-Automation Role and Techniques	Advanced automation concerns the automated support to design of a new ATM concept in order to achieve the required performance levels. The new concept is related to the dynamic selection of sector collapsing/decollapsing configuration, based on the planned traffic. The decision-support approach is simulation-based since the approach applies computational intelligence techniques for carrying out offline simulations to performing what-if analyses of ATM changes and to optimise the design of new solutions.

AI-based	No
Maturity	
TRL	2
Available Validation Activities	The achieved validation activities are those related to the SESAR EVOAtm project, which was an exploratory research project and an application-oriented research, providing results complying with a TRL 2 (Technology concept and/or application formulated).
Available Safety Analysis	None.
Available Certification Activities	None.
Human Factor Analysis	
OPS Supervisor – Flow Manager	Key Role, Tasks and Responsibilities: *Minimal Impact* (2/5) Key Tools: *Minimal Impact* (2/5) Communication: *No impact* (1/5) Organisation and Planning: *No impact* (1/5)
LOAT Assessment	
Function 1 – Sector collapsing/decollapsing simulation – To simulate a given sector collapsing/decollapsing configuration in ATM by means of ABMS with the following agents: ECs and PCs across multiple sectors; CWPs; aircraft; FCs. **LOAT: 0**. **Function 2 – Sector collapsing/decollapsing optimisation** – To compute the collapsing/decollapsing configuration in ATM (PC/EC allocation) by means of AES for optimising controller workload in terms of total number and standard deviation of: EC communication to FC; EC separation actions; PC separation actions. **LOAT: 1 or 2.**	
Items to Be Certified	
Software: Tool implementing ABMS and AES for the dynamic design of sector collapsing/decollapsing configurations.	

A.2 Case Study 2: AI-Powered Digital Assistant in TMA

Table 18. Form of case study 2.

Case Study 2	**AI-Powered Digital Assistant in TMA**
Reference Project	
Project Summary	**NUVASC** The case study leverages on a proof of concept developed in an Italian National Project, NUVASC, funded by the Ministry of Education for the period 2020-2026. The Project NUVASC has been structured in different phases and has covered different use cases focusing on AI in aviation. NUVASC Use Case1 developed in 2022-2023 is the DA – referred to as ACOP (Arrival digital assistant with Conflict Prevention) – and considered in HUCAN. The research project has been supported in kind by ENAV. The requirements

	have been collected by interviewing ENAV operational staff and a preliminary validation in a laboratory has been conducted and submitted to ENAV and results have been shared.
Project Timeline	2020 – 2026
References	https://doi.org/10.3390/info14040216
Contacts	Gabriella Gigante (CIRA) – g.gigante@cira.it
Description	
Purpose	This case study presents a digital assistant supporting the ATCO in aircraft sequencing by providing suggestions for next waypoints, speed adjustments and altitude holdings. On the one hand, the suggested paths are such to preserve safety by ensuring the prescribed minimum separation, while also promoting environmental benefits through continuous descent operations (CDO). On the other hand, the suggestions aim to reduce landing times, improving the runway throughput. The proposed case study exploits multipath planning, for which a global optimisation technique is used in conjunction with the dynamic time warping distance metric and a reinforcement learning approach to resolve conflicts through speed modulation and/or altitude holding. The DA aims at modelling AI algorithms to support the controller in decision making when applying final approach procedures (e.g., Point Merge System trombone routes). Considering the Trombone procedure, aircraft join the final approach via a fixed path. Sequencing is achieved through a single direct-to instruction issued to each aircraft along the legs, as soon as the required spacing with the preceding aircraft is obtained. When traffic permits, aircraft are cleared to the point without using the legs. The tactical instruction is provided by the controller relying on their experience. The proof of concept aims to support controllers in providing such tactical instructions. Deep RL techniques are applied to learn how to map situations to “direct to” instructions and to understand which are the most rewarding ones. The reward signal is related to some key performance indicators, such as safety, capacity and environment.
High-Automation Role and Techniques	The ACOP is structured in layers acting on different tasks sequencing and scheduling layer (SSL) and the conflict management layer (CML). The SSL is implemented by means of: a genetic algorithm whose cost function to be minimised is assumed to be the sum of the estimated times of arrival (ETA) of each aircraft; dynamic time warping (DTW) algorithm to select among the multiple solutions provided by the optimisation step. The scenario with the largest average DTW value is selected and proposed to the controller. The CML is composed of two different sub-functions: conflict detection between all possible pairs of aircraft and; conflict resolution to separate aircraft by reducing speed and/or holding altitude. Conflict resolution function is implemented by means of Reinforcement Learning. In the CR, only two actions are supposed to be available: speed reduction and altitude holding. When a potential conflict is detected, the trained AI model is called and returns an appropriate speed reduction for one aircraft only. If the RL solution results in a velocity value outside the allowable range, this means that speed reduction is not a feasible way to prevent the conflict, and another approach must be considered.
AI-based	Yes
Maturity	

TRL	3
Available Validation Activities	At the current step in the maturation process, active research and development has been initiated, considering both analytical studies to set the technology into an appropriate context and laboratory based studies to physically validate that the analytical analysis have been correct.
Available Safety Analysis	None.
Available Certification Activities	None.
Human Factor Analysis	
Planner Controllers & Executive Controllers	Key Role, Tasks and Responsibilities: *Moderate Impact* (3/5) Key Tools: *Very High Impact* (5/5) Communication: *No impact* (1/5) Organisation and Planning: *No impact* (1/5)
LOAT Assessment	
Function 1 – Conflict detection – To detect conflicts between all possible pairs of aircraft. **LOAT: 0 or 3 or 4**. **Function 2 – Sequencing and scheduling optimisation** – To sequence and schedule aircraft arrival by minimising the times of arrival. **LOAT: 1 or 2.** **Function 3 – Conflict resolution** – To compute conflict-resolution actions for separating aircraft by reducing speed and/or holding altitude. **LOAT: 1 or 2.**	
Items to Be Certified	
Software: Tool implementing the DA for supporting the ATCOs in conflict detection, sequencing and scheduling optimisation, and conflict resolution. Operators: Training/license for PCs and ECs in regard to the usage of the support provided by the DA.	

A.3 Case Study 3: Dynamic Airspace Reconfiguration Service for U-Space

Table 19. Form of case study 3.

Case Study 3	**Dynamic Airspace Reconfiguration Service for U-Space**
Reference Projects	
Projects Summary	**ENSURE – ATM-U-space Interface and Airspace Reconfiguration Service** This project aims to refine and complete the definition of a common interface and services for U-space and ATM. The project will develop a standardised data model, architecture and an operational methodology. The project will also develop a dynamic airspace configuration service to help ATC actors in charge of airspace reconfigurations to maintain traffic segregation and to avoid proximity between manned and unmanned aircraft within the designated U-space airspace.
Project Timeline	2023-06-01 > 2026-05-31

References	https://sesar.eu/projects/ensure
Contacts	giovanni.riccardi.1@enav.it
Description	
Purpose	The dynamic airspace reconfiguration service involves modifying U-space volumes and exchanging information between ATM and U-space to define new airspace boundaries. In controlled airspace, ANSPs remain responsible for providing air navigation services to manned aircraft operators within designated U-space areas. ANSPs also conduct dynamic reconfiguration of U-space airspace to ensure the safe segregation of manned and unmanned aircraft. In this context, ATC units will temporarily limit areas within designated U-space airspace where UAS operations can occur to accommodate short-term changes in manned traffic demand by adjusting the lateral and vertical limits of U-space airspace. They will also ensure timely and effective notification of relevant U-space service providers and single CISPs regarding the activation, deactivation, and temporary limitations of designated U-space airspace. Supporting tools and AI applications will assist ATCOs in determining the best solutions and configurations for managing operations. These tools will process data from various sources (ATM, USSP) to provide optimal settings in terms of capacity, predictability, safety, efficiency, and environmental sustainability.
High-Automation Role and Techniques	Dynamic Airspace Reconfiguration (DAR) involves the real-time adjustment of airspace boundaries, to accommodate changing traffic patterns, weather conditions, or security concerns within a U-space airspace volume in controlled airspace. An AI could play the role of a DAR Manager, or at least, as a support, by leveraging its capabilities in data analysis, pattern recognition, predictive modelling, and decision-making.
AI-based	Yes
Maturity	
TRL	1
Available Validation Activities	None.
Available Safety Analysis	None.
Available Certification Activities	None.
Human Factor Analysis	
Dynamic Airspace Reconfiguration Manager	Key Role, Tasks and Responsibilities: *Moderate Impact (3/5)* Key Tools: *Very High Impact (5/5)* Communication: *Minimal Impact (2/5)* Organisation and Planning: *No Impact (1/5)*
LOAT Assessment	
Function 1 – Data collection and processing – To identify the current traffic condition, by analysing both internal and external data sources. **LOAT: 0**.	

Function 2 – Pattern recognition and prediction – To recognise and predict future airspace congestion. **LOAT: 0 or 3 or 4.**

Function 3 – Real-time decision support and adaptation – To provide the human operator with the recommendation for the optimal reconfiguration, based on: scenario model, its simulation, real-time updates, historical data for the impact prediction of the proposed solution. **LOAT: 1 or 2.**

Items to Be Certified
Software: Tool to support DARM for DAR.
Operation: Process involving DAR with reference to ATC and the DARM operator.

A.4 Case Study 4: Dynamic Allocation of Traffic between ATCO and System

Table 20. Form of case study 4.

Case Study 4	**Dynamic Allocation of Traffic between ATCO and System**
Reference Project	
Project Summary	ARGOS represents MUAC's vision for its next-generation ATC system. While current aids to ATCOs are limited to the detection of conflicts, the future system will be able not only to propose a set of conflict-free solutions, but also to indicate to ATCOs those which are optimal, and even to apply them autonomously under certain conditions (e.g., night traffic).
Project Timeline	2022 – ongoing
References	https://www.eurocontrol.int/publication/argos-factsheet
Contacts	Peter Hendrickx, MUAC
Description	
Purpose	The purpose of ARGOS is to support ATCOs in managing traffic in their sectors by means of a dynamic allocation of airspace management between the ATCO and the system in en-route airspace.
High-Automation Role and Techniques	ARGOS issues suggestions to the controller working position (CWP). On the CWP, the ATCO can decide whether to let the system issue the clearances automatically through CPDLC or to take its suggestions on board and handle the traffic manually. There are three modes of operation in ARGOS: • L3: decision support tool mode: intuitive conflict resolution overviews and optimal trajectory proposals. • L5: hybrid mode of operation: L3 + simple CPDLC flight handling upon ATCO approval. • L8: automated mode of operation: low-traffic sector handling without ATCO supervision. L8 assumes full deployment of CPDLC capabilities on the ground and on board the aircraft. The other modes of operation can still be applied in case not all aircraft are connected to CPDLC, with the limitation that non-CPDLC aircraft can only benefit from ARGOS as a decision support tool (L3). In L8, the final goal is to remove the need for ATCO supervision of the system handling the basic traffic. The ATCO will remain available to supervise the system when the system indicates the need for help. To

	achieve this level of automation, ARGOS solutions will be such that, in case of an unforeseen event (aircraft loses CPDLC, does not execute a clearance within 2 minutes, etc.), the traffic situation remains safe for a defined period while the ATCO is brought back into the loop.
AI-based	No – AI or machine learning (ML) models will not be used for the conflict resolution itself, that is, in the decision and execution phases. Nevertheless, certain components of the deterministic resolution could make use of a ML model in the data perception and analysis phases, such as the calculation of variable speed and/or climb/descent rate in the trajectories.
Maturity	
TRL	4
Available Validation Activities	Yes – Internal
Available Safety Analysis	Yes – Internal
Available Certification Activities	N/A
Human Factor Analysis	
Room Supervisor	Key Role, Tasks and Responsibilities: *Very Highly Impact (5/5)* Key Tools: *Very High Impact (5/5)* Communication: *Very High Impact (5/5)* Organisation and Planning: *Moderate Impact (3/5)*
Executive and Coordinator Controller (ATCO)	Key Role, Tasks and Responsibilities: *Very High Impact (5/5)* Key Tools: *Very High Impact (5/5)* Communication: *Moderate Impact (3/5)* Organisation and Planning: *Moderate Impact (3/5)*
LOAT Assessment	
L1 for ARGOS used in Decision Support Tool mode of operations L3 for ARGOS used in hybrid mode o operations L4 for ARGOS used in automated mode of operations	
Items to Be Certified	
Software: Tool supporting the ATCOs in managing traffic by means of a dynamic allocation of airspace management between the ATCO and the system in en-route airspace, including three different modes of operation (decision support, hybrid, automated). Operators: Training/license for ATCOs in regard to the usage of the support provided by the tool. Operations: Approval of the new operational procedures, also including the transitions amongst the three modes of operation (decision support, hybrid, automated) and the related ATCO engagement.	