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TAPAS

TOWARDS AN AUTOMATED AND EXPLAINABLE ATM SYSTEM

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Abstract

This document presents the final version of the TAPAS deliverable D6.3 Final Project Results Report. It contains the final results of the ATFCM and CD&R experiments carried out under the umbrella of TAPAS project. This includes a general description of the eXplainable Artificial Intelligence (XAI) and the Visual Analytics (VA) prototypes especially developed for each use case, the results obtained during the validations exercises performed and the conclusions gathered related to the transparency and explainability requirements for the application of AI/ML automation tools in the ATM domain.

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1 Executive Summary

TAPAS (Towards an Automated and exPlainable ATM System) is a research project funded by the SESAR Joint Undertaking within the European Unions's Horizon 2020 research and innovation programme under grant agreement No 892358. Particularly TAPAS addresses the Research Topic SESAR-ER4-01-2019 "Digitalisation and Automation principles for ATM". TAPAS is an exploratory research project aiming at achieving TRL1/2.

TAPAS is led by CRIDA, the R&D+I Centre of the Spanish Air Navigation Service Provider (ENAIRE), and with participation from BOEING, FRAUNHOFER, ISA SOFTWARE, UNIVERSITY OF PIRAEUS and INDRA.

The deployment of AI-based tools is becoming commonplace in many aspects of our daily lives, and Air Traffic Management (ATM) is no exception to this phenomenon. In practice, as the ATM system is becoming increasingly saturated, enhanced tools which employ AI techniques are being considered to help to increase the capacity and resilience of the system through higher levels of automation.

TAPAS addresses the effectiveness of introducing AI/ML solutions to increase the levels of automation in ATM, considering the need of the operator to trust the system (taken as the ability to understand and explain its behaviour and outcomes).

The main objective for the project is the exploration of highly automated XAI scenarios through validation activities and Visual Analytics (VA), to identify needs and strategies to address transparency and explainability in the operational cases considered, paving the way for the application of these AI/ML technologies in ATM environments, in particular in automation levels 2 and 3 as expressed in the successive editions of the European ATM Master Plan [21].

In support of this objective, a set of validation experiments were performed that included prototype DST working at varying levels of automation, ranging from the provision of advisory information to the automated execution of actions identified by the DST. These tools were accompanied by a dedicated set of transparency tools, which provided interactive Visual Analytics (VA) and explanatory information (XAI tool), designed to help the human operator to understand the proposed decisions and, consequently trust the system.

As a part of the validation process, subjective qualitative and objective quantitative data has been collected from a series of Human in the Loop (HITL) simulation experiments**.** These have been analysed to assess the TAPAS concept and research goals as expressed in the validation plan, with a strong focus on identifying principles and recommendations relating to transparency needs when using AI solutions.

In the initial scenarios, the focus was on the ATFCM domain with XAI based DST providing automated recommendations at levels of automation ranging from Level 1 to Level 3. A Visual Analytics support tool and a prototype FMP client application were also used to assist the human operators for explainability and transparency for simulation scenarios. The second set of experiments provided automated AI based support in the Conflict Detection and Resolution (CD&R) activity provided by the ATC Radar/Executive controller with DST also running at the three different levels of automation. The XAI based CD&R automation was used to identify conflict situations, provide recommended actions, and support conformance monitoring to help users solve ATC problems in real-time experiments conducted using the ENAIRE/CRIDA SACTA ATC simulator platform.

The validation experiments led to a set of relevant principles and recommendations to be considered regarding the application of transparent and explainable Artificial Intelligence (AI) in the automation of Air Traffic Flow and Capacity Management (ATFCM) and Conflict Detection and Resolution (CD&R) use cases.

Some innovative ideas and principles to be considered when automating, at different levels, ATFCM and CD&R use cases using technology based on Explainable AI (XAI) and Visual Analytics (VA) were obtained. In general, these principles and recommendations contain revealing knowledge which is supposed to serve as reinforcement for conducting air traffic management tasks more fluently, efficiently, safely and robustly for the user. These principles and recommendations have been elaborated based on three important sources of knowledge gathered during the development of the TAPAS project: i) valuable feedback collected from different experts in Air Traffic Management (ATM), human factors and AI fields; ii) lessons learned through the development and implementation of the transparency requirements defined at the beginning of the project, which served as a guide and beacon for the technical implementation of the prototype; and iii) results from the validation activities of a set of expert operators when using and interacting with the prototypes developed for the ATFCM and CD&R use cases. From these three activities, multiple and diverse ideas, feedback, conclusions and insights were extracted which have served to elaborate and shape these principles and recommendations for transparency in AI/ML automation in ATM.

The main conclusions obtained are:

1. Rather than detailed explanations on the solutions proposed by the XAI tool, the user needs to trust the system. Also, that trust can be lost very rapidly and rebuilding it can be hard.

2. The traceability of explanations is key for transparency. The user needs, not only to see the final explanation of the solutions but have a clear traceability of the elements related to each measure/solution.

3. Different levels of explainability are necessary according to the time horizon considered. Users require different amounts of explanations on specific solutions given by the XAI, depending on whether they are immersed in the operation or training (-pre) stages.

This new knowledge is intended to pave the way towards the uptake of AI/ML techniques as a step towards higher levels of Automation in accordance with the ATM Master Plan [21], as well as to serve as a general basis and a guideline in the application of transparent AI methods in ATM scenarios.

2 Project Overview

2.1 Operational/Technical Context

2.1.1 Problem addressed by the project

TAPAS (Towards an Automated and exPlainable ATM System) addresses the effectiveness of introducing AI/ML solutions in order to increase the levels of automation in ATM, considering the need of the operator to trust the system (taken as the ability to understand and explain its behaviour and outcomes).

The main objective for the project is the exploration of highly automated XAI scenarios through validation activities and Visual Analytics (VA), in order to identify needs and strategies to address transparency and explainability in the operational cases considered, paving the way for the application of these AI/ML technologies in ATM environments, in particular in automation levels 2 and 3 as expressed in the successive editions of the European ATM Master Plan.

2.1.2 Operational Environment

Within the Air Navigation Services domain, the TAPAS project focus specifically on Air Traffic Flow and Capacity Management (ATFCM) and Air Traffic Control (ATC) Services.

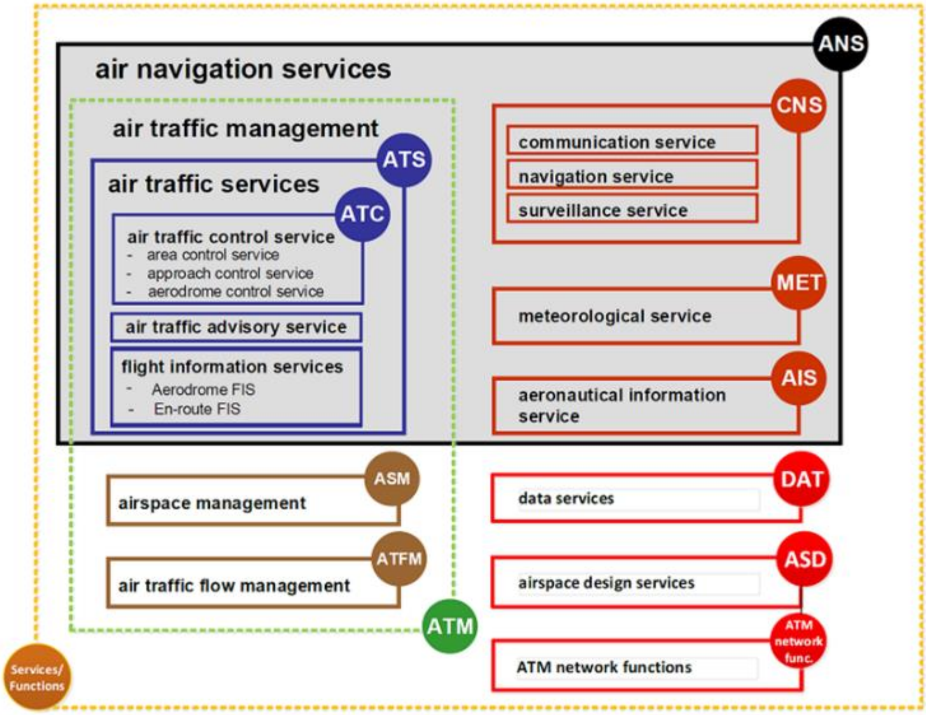

Figure 1: Air Navigation Services (EASA)

The following operational concepts support TAPAS ATFCM and CD&R use Cases. To this end, the vision of the SESAR programme has been considered.

- **Trajectory Based Operations (TBO).** The concept of Trajectory Based Operations (TBO) consists in allowing airspace users to fly their preferred trajectories to deliver passengers and goods on time to their destination as cost-efficiently as possible.

  TBO relies on a full integration of flight information, enabling the ATM system to have a synchronised view of the flight data by all the stakeholders involved. According to the SESAR Concept Of Operations (CONOPS), high quality 4D trajectories data will be made automatically available to all relevant stakeholders by means of cutting-edge ground-ground trajectory exchange mechanisms. This will improve common situational awareness, automation and global performance.

  It is also expected that TBO will enable increased collaboration and operational predictability, by means of enhanced collaborative decision-making processes [24]. TBO will facilitate a fundamental shift away from flight management through Air Traffic Control tactical interventions towards a more strategic focus on trajectory planning and intervention by exception [25].

- **Free-Route Operations.** Free Route Operations, that is, flights following as direct routes as possible between the origin and destination, are enabled by the introduction of higher levels of automation in support of the following processes [26]:

  - Wide implementation of automated tools for conflict detection and resolution, flight monitoring, and electronic coordination;
  - Enhanced ATFCM with Integrated Network ATC Planning (INAP) offering a more optimised granularity level for complexity management and Dynamic Airspace Configuration (DAC) management;
  - Advanced processes for airspace management, including Dynamic Airspace Configuration;
  - Flight and flow centric operations.

  The result is an airspace that is managed as a continuum, allowing a better use of airspace capacity, and supporting an optimum demand-capacity balancing process by offering much more flexibility for flight profiles optimisation based on user preferred trajectories.

  With free route airspace in high and very high complexity cross-border environments, the use of Conflict Detection and Resolution support tools is considered mandatory to support the Planning and Tactical Separation assurance.

- **Dynamic Airspace Configuration (DAC).** DAC is part of the SESAR 2020 Advanced Demand and Capacity Balancing concept, with enhanced and fully integrated processes that ensures that all levels of the network can manage their operations across all ATM phases to meet performance targets in a seamless and fully collaborative basis [3].

  In comparison with a sectorisation based on a fixed route network, with little flexibility to meet demand requirements, the DAC concept introduces the idea of User Preferred Routes and new type of flexible airspace reservations (Dynamic Mobile Areas - DMA). The objective is to develop airspace designs and sector configuration schemes in order to optimise the use of the available capacity and balance the Air Traffic Controller (ATCO) workload avoiding unnecessary intervention on the traffic flows.

In the DAC environment, the number of controlled sectors and their shape can be adapted to the current traffic situation at all ATM planning phases, from long term to execution. Thus, the DAC process aims at identifying an optimised sector configuration based on the traffic demand and predicted complexity, ATCOs availability, and predefined performance targets.

- **Flight Centric ATC Concept (FCA).** In the Flight Centric ATC concept, ATCOs are no longer responsible for managing the entire traffic within a given sector, but rather for managing a certain number of aircraft throughout their flight segment within a larger airspace or along flows of traffic. This means that aircraft may be under the responsibility of the same ATCO across two or more geographical sectors [28].

  In terms of airspace, the FCA concept will dissolve the current sector boundaries for managing separation provision across several sectors, to enable larger sectors to be used (e.g., the new airspace distribution could be done at the level of Area Control Centres or Functional Airspace Blocks (FAB)).

  The change to a flight-centric structure, without reference to geographical sectors, will open the opportunity to better distribute the traffic and to avoid the loss of productivity in under-loaded sectors. Other benefits are also expected, such as reduced fuel consumption and emissions, enhanced predictability, improved operational and cost efficiency and maintained levels of safety.

2.1.3 Technical Context

The concept of trustworthiness in AI has special relevance in the context of ATM. In June 2018, the European Commission (EC) set up a High-Level Expert Group on AI that proposed the following seven key requirements for trustworthy AI, which were published in its report on Ethics Guidelines on AI [4]:

- Accountability
- Robustness and safety
- Oversight
- Privacy and data governance
- Non discrimination
- Environmental well being
- Transparency

The trustworthiness concept has been meant to be a key enabler of the societal acceptance of AI. TAPAS project hasexplored and addressed the concept of transparency, as key element for trustworthy automation of different ATM operational scenarios. Explainable AI (XAI) and Visual Analytics (VA) still stand out as very promising technologies to achieve this automation in trustable manners: in fact, its value has been confirmed in the project results. Thus, these technologies have been proved to have a key relevance during the automation of the activities involved during two ATM use cases: ATFCM and CD&R.

2.2 Project Scope and Objectives

The scope of TAPAS is the systematic exploration of AI/ML solutions towards increasing levels of automation in specific ATM scenarios, through analysis and experimental activities, with the objective to deliver principles of transparency, enabling the application of AI/ML supported automation in ATM. Specifically, TAPAS intended to:

- Describe and analyse in detail two operational cases: Conflict Detection & Resolution applied to Air Traffic Control (ATC, tactical), and Air Traffic Flow Management (ATFM, pre-tactical).
- Develop eXplainable Artificial Intelligence (XAI) methods, addressing the requirements of both operational cases, which focus on the needs of operators (and potential other actors) concerning the quality and transparency of solutions generated by XAI methods.
- Apply Visual Analytics techniques to assess and enhance explainability of AI/ML systems in ATM.
- Run experiments that assess the applicability of XAI methods in the various levels of automation considered, exploring different ways of interaction and information exchange. The objective was to understand how operators (and potential other actors) increase their trust to XAI methods.
- **Extract conclusions, principles and recommendations** based on these experimental results and analysis, which will serve as an enabler for the implementation of XAI methods in higher levels of automation in ATM.

The main goal of TAPAS was the exploration of highly automated XAI (eXplainable Artificial Intelligence) scenarios through validation activities and Visual Analytics (VA), in order to identify needs and strategies to address transparency and explainability in the operational cases considered, paving the way for the application of these AI/ML technologies in ATM environments.

This reflected in two main objectives (in alignment with the Project Management Plan):

1. **Identification of principles and criteria for AI/ML transparency/explainability**[1] **in ATM domain scenarios**, based on the two operational cases considered and with the target to identify transparency requirements for AI/ML methods in general, limiting domain-specific results.

   The project expected to explore the use of XAI and VA to apply them in the operational cases considered, through practical experiments and validation activities in simulation platforms. In particular, for each level of automation considered in each operational case, the project searched to implement a distribution of functionalities between the human and the machine including AI/ML ones. These would be verified using different validation techniques such as

[1] Transparency and explainability are considered as synonyms in this context

real-time simulation and gaming, combined evaluation of operators a-priori and a-posteriori expert judgement, and objective criteria verification.

Success Criteria: This objective would be considered accomplished when:

- The roadmap for function distribution per automation level in each operational scenario is set
- The criteria for explainability of AI/ML methods are identified and experimentally verified for the different levels of automation being considered, and for the different actors involved (as explainability might not only be needed for system operators). This will include recommendations for certification of such functionalities.

2. **Selection and development of suitable and explainable AI/ML methods in the operational cases** identified, to fit the needs of transparency as expressed in the explainability criteria developed for each automation level and according to actors' needs. Given the early Technology Readiness Level (TRL) of this project (pre-TRL 1), these prototypes would be focused on testing purposes.

   Success Criteria: This objective would be considered accomplished when:

   - The identified AI/ML based functionalities are implemented in the testing environments allowing evaluation of their explainability versus effectiveness in practice.
   - The different techniques used or explored can be categorized in terms of general suitability (combining effectiveness and explainability) for the operational cases considered.

2.3 Work Performed

The work carried out in the TAPAS project is framed within the two different objectives detailed above**:**

- Identification of principles and criteria for AI/ML transparency/explainability in ATM domain scenarios
- Selection and development of suitable and explainable AI/ML methods in the operational cases identified

2.3.1 Identification of principles and criteria for AI/ML transparency/explainability in ATM domain scenarios

This objective applies to the two operational cases considered (ATFCM – Air Traffic Flow and Capacity Management; and CD&R – Conflict Detection and Resolution) and with the target to identify transparency requirements for AI/ML methods in general, limiting domain-specific results.

The strategy to achieve this goal is based in addressing different temporal, functional and safety-critical perspectives, as those provided by the complementary operational cases considered in TAPAS. It is the ambition of the project to maximise the applicability of results to different operational environments, while setting the limitations when this is not feasible.

The project explores the use of XAI and VA to apply them in the operational cases considered, through practical experiments and validation activities in simulation platforms. In particular, for each level of automation considered in each operational case, the project implements a distribution of functionalities between the human and the machine including AI/ML ones. These are verified using real-time simulations (RTS) including operational staff (Air Traffic Controllers) both providing a-priori and a-posteriori expert judgement, and objective criteria verification.

Since the beginning of the project, intense and significant work has been performed in order to provide the earliest possible operational roadmap and transparency requirements allowing the effective development of XAI and Visual Analytics prototype to support the use cases. For further detail on the roadmap adopted and the transparency requirements defined, please consult deliverables D2.2 Consolidated Requirements and Functional Roadmap [7] and D3.1 use Cases Transparency Requirements [8].

In parallel, the specification of transparency requirements to be built on top of functional ones in the XAI implementations have been completed for both use cases in due time according to the plan. This has enabled the development of prototypes to conduct the first round of ATFCM experiments with operational staff in June 2021, verifying the requirements and as initial step for recommendations and elaboration of a transparency framework. All the specification for the second use case (CD&R) were also concluded once this exercise was executed in March 2022. More details on the transparency principals extracted from the experience in both ATFCM and CD&R use cases can be consulted in deliverable D3.2 Principles for Transparency in AI/ML Automation [9].

2.3.2 Selection and development of suitable and explainable AI/ML methods in the operational cases identified

This selection has the goal to fit the needs of transparency as expressed in the explainability criteria developed for each automation level and according to actors' needs.

The project developed prototypes of XAI methods which address the balance between explainability and effectiveness according to specific needs, but also in search of developing a more general taxonomy of AI/ML techniques considering the two mentioned magnitudes. Given the early Technology Readiness Level (TRL) of this project (pre-TRL 1), these prototypes were focused on testing purposes.

WP4 has analysed, selected and developed the XAI methodologies to support the ATFCM and CD&R use cases, as described in D4.2 Reference of XAI Methods [11].

The VA modules that were developed for the ATFCM and CD&R use cases in TAPAS work in combination with the XAI components as an integrated prototype (D4.1 TAPAS Integrated Prototype [10]).

In particular for the ATFCM use case, the XAI components develop solutions for demand-capacity imbalance problems while the VA component provides additional support to allow users to explore the problems being addressed and the solutions that have been proposed.

In this integrated solution, the VA component is used to help ATFCM operators to:

- Understand why problems, such as demand-capacity imbalances, have been identified by the automated system.

- Explore the reasons, through visual representation, why the proposed solution is appropriate for the problem

- Help the human to understanding how solutions developed by the ML/AI component were determined

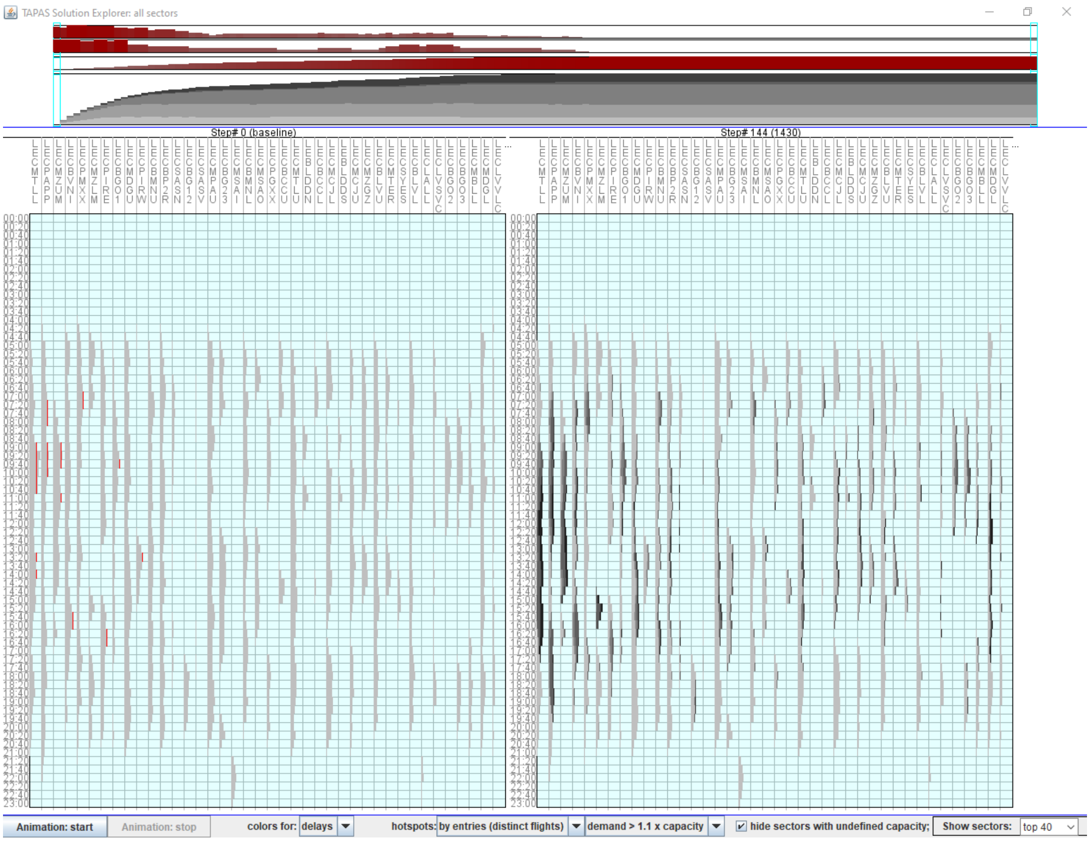

Figure 2: Snapshot of the VA tool for the ATFCM use case

For the CD&R exercises, the VA tool is also integrated with the ML/XAI component and connected to the ATC platform (see D4.1 TAPAS Integrated Prototype [10]). In this case, the VA component supports the ATCO in the following analytical tasks:

- Awareness of potential conflicts in the following 7-10 minutes between flights inside the sector of focus and in the immediate exit area of that sector.

- Understanding of the conflicts detected, including their severity and main characteristics:
  - Flight IDs and attitude of the aircraft involved in the conflict.
  - Horizontal and vertical separation at the start of the infringement point, closest point (CPA) and at the end point.
  - Time of the potential conflict, at the start, CPA and at the end of conflict.

- Conflicts associated with the new detected conflict, whenever it comes from a previous detected one or other resolution action proposed.
- Severity scores of the conflict and Measure of Compliance with the separation minima required.
- 2D visualisation of the conflicts together with a representation in the Z axis.

* Explore solutions proposed by the XAI algorithm for the specific conflicts. The solutions (direct to a WP, change of HDG/FL/speed) are presented through a tab and arranged in a ranking list from best to worst solution.
* Impact metrics relating to each solution proposed are also included in the listed solutions.
* Awareness of non-conformance monitoring events through a pop-up window showing the aircraft and related condition/s that has/have been violated according to the last available FPL.

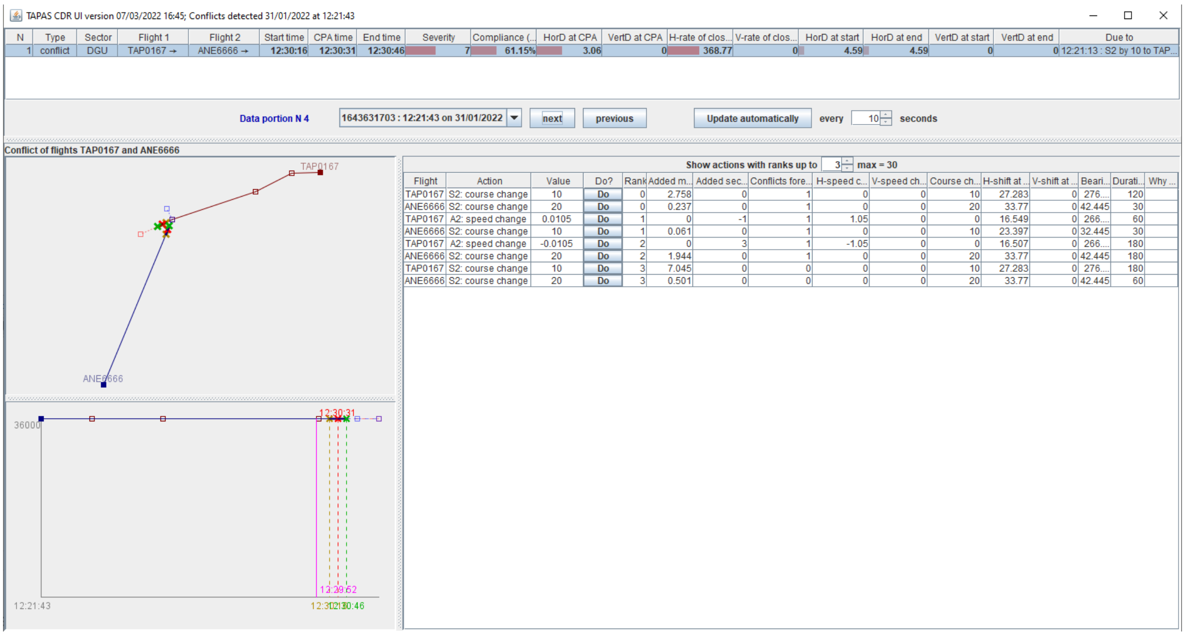

Figure 3: Snapshot of the VA tool for the CD&R use case

For a more detailed description of the VA prototypes developed within TAPAS project readers should refer to D4.3 Visualizations and Visual Analytics Methods [12].

2.3.3 Validation Exercises

Apart from the transparency/explainability criteria and the XAI and VA prototypes, the work performed within TAPAS project also included two validation exercises for ATFCM and CD&R use cases conducted in June 2021 and March 2022, respectively (see D5.2 Validation Report [14]).

First, a Validation Plan was defined to set the framework for all the research activities and exercises that have been performed by the members of the TAPAS project in two main domains:

- ATFCM – with a focus on Demand-Capacity Management activities to solve load imbalances in the planning phases of ATM network management, using XAI-based automation with VA to support transparency and explainability.

- ATC– applying XAI and VA techniques to support automated Conflict Detection and Resolution processes during the execution of aircraft flight plans.

The objectives of the validation, along with any assumptions, and a description of the exercises to be performed are provided in more detail in D5.1 Validation Plan [13].

The different domains are addressed using two independent sets of validation experiments, held at different times during the research project.

The ATFCM experiments aimed to allow human operators to work interactively in a realistic pre-tactical network capacity planning environment at different levels of automation (levels 1 – 3). The operators were asked to identify and solve overloads during the ATFCM planning phase either manually (level 1), with partial automation (level 2) where possible solutions are identified but the operator maintains the control of whether to apply them or not, and full automation (level 3) where proposed solutions are automatically executed by the tools.

The focus of the experiments was on the regional Flow Management Position - FMP (also known as the Local Traffic Manager - LTM) and, in line with the VALP, the objectives were to understand if situational awareness and understanding of the problems identified or being solved by the AI tool was sufficiently supported through the explainability and visual analytics components.

The ATC CD&R experiments offer a much more challenging environment within which to deploy the AI-based automation support tools. The aim of the CD&R to allow human operators to work interactively in a realistic ATC environment where the DST provides conflict alerting and, according to the level of automation (levels 1 – 3), recommendations for potential clearances that would solve those issues, or at the highest level, solve those issue automatically without ATCo intervention. The challenge in this role was the short lead time between detection of a problem and the necessary actions needed to resolve those issues - which needed to be performed in a very short time-window leading up to the identified separation problems. With such a short timeframe, beyond which safety could be compromised, the content of the VA 'explainability' elements needed to be very concise and provide information rapidly to the user, in a manner that could be quickly and easily understood. Furthermore, with such a short timeframe between the identification of the conflict and the need to provide suitable clearance(s) little or no time was available to allow the user to *drill down* into the VA support tools to discover more detailed information.

During the exercises, operators were asked to either identify and solve conflicts in the controlled sector, either manually (level 1), with partial automation (level 2) where possible solutions are identified but the operator maintains the choice of which solution(s) to consider/apply or not, and full automation (level 3) where proposed solutions are automatically executed by the tools.

The focus of the experiments was on the Executive/Radar Controller Position, and in line with the VALP, the objectives were once again to understand if situational awareness and understanding of the problems identified or being solved by the AI tool was sufficiently supported through the explainability and visual analytics components but in the CD&R case, with significant time constraints on the overall process.

The TAPAS VALP also provides traceability between the validation and the research objectives, by setting the relationship between the TAPAS ATFCM and CD&R Use Cases and the corresponding Validation Exercises.

ATFCM use case execution

A total of eight (8) individual exercises were performed using the platform. It should be noted that the first two exercises were executed with a heavy focus on training purposes, to ensure that the FMP experts could acquire sufficient knowledge and familiarity with the DSTs and the platform that was used during the different sessions. Interim sessions were aimed at enhancing the FMP familiarity with the platform and the associated DST running at different levels of automation.

The final day of the experiment included execution of the platform at each of the levels of automation to allow the FMP users to operate in scenarios with increasing levels of automation, and since time permitted, included a second scenario running at full automation to allow the FMP to delve deeper into the VA support component and its capabilities. At the end of each exercise a debrief session was held and the FMP completed a questionnaire about the experience.

CD&R use case execution

Regarding the TAPAS CD&R validation, three different scenarios were considered based on the levels of automation tackled by the project, namely automation level 1, 2 and 3 (section 5.4 of VALP [13]).

The validation took place over a period of three days, with exercises on Day 1 focused on the provision of training to the users as well as to ensure they became familiar with the various XAI and VA solutions provided as part of the validation process. Days 2 and 3 were used to run the full validation scenarios and to assess the effect on human performance and understanding when using the XAI and VA tools at different levels of automation. One of the two selected sectors from the Madrid ACC – Toledo Upper (TLU) and Domingo Upper (DGU) was used as the measured sector in each scenario.

The original experimental planning included: 3 scenarios executed at Level 1 automation (*one per day*), 3 scenarios at Level 2 automation (*one per day*) and 5 exercises running at Level 3 automation with the ATCO working in only a *monitoring mode*.

However, following the verification phase of the CD&R activity, which included running scenarios with ATC experts from ENAIRE and getting their feedback on the proposed exercises, it was decided to reduce the number of exercises running in Level 3 (‘full automation’) for a variety of reasons, including the performance of the XAI tool in ‘full’ automation mode and time limitations when the ENAIRE ATC experts were not available. From a technical perspective, the XAI solutions did not always solve all the conflicts that occurred in the scenarios. Therefore, this meant that all the Level 3 scenarios that were executed already included some type of “*system failure/ATCO recovery of control*” component, which eventually resulted in the scenario reverting to automation Level 2. Hence due to this view of the automation, and the time constraints on the availability of domain experts, it was decided to reduce number of Level 3 runs from (from 5 to 3) rather than impacting scenarios at the other levels and more focus was placed on Level 2.

At the end of each exercise a debrief session was held and the Controller completed a questionnaire about the experience.

2.4 Key Project Results

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2.4.1 ATFCM use case

The table below summarises the validation results against the stated objectives that were obtained from the ATFCM validation scenarios:

Table 1: Summary of ATFCM Validation Exercises Result

TAPAS ATFCM Validation Objective	Sub-Focus	Success Criterion	Validation Results	Status
OBJ 1: Identify principles for Transparency of AI-based solutions	1.1 Determine how much additional information is needed at automation levels 2 & 3 to ensure that the human operator is able to make informed decisions to help solve ATM problems.	VA and explanatory support information is clear and understandable and the tools are able to provide the required information at the right time.	Users were able to access and consult the VA display and associated information very easily and in an interactive manner. Information was provided in a timely fashion via the VA display and helped users to maintain their Situational Awareness. Explanations provided via the VA component were generally clear, but some issues to understand solutions being proposed were highlighted.	**POK**
	1.2 Identify when support information is required, what level of detail is needed and how should it be provided in a timely manner.	Key data that can be easily understood by the human has been identified that supports transparency needs and is provided in the required time frame and at an appropriate frequency	During the initial training scenarios held on day 1 (level 2 partial automation) and day 2 (level 3 full automation) and for the final day 3 exercises, users reported that the ***effort to scan both the FMP and VA displays was low***. However, ***understanding the XAI solutions was considered poor***, particularly at level 2 (partial automation). ***Effort required to gather and interpret information was initially considered high but***	**POK**

TAPAS ATFCM Validation Objective	Sub-Focus	Success Criterion	Validation Results	Status
			improved as the users became familiar with the VA display and its available features.	
	1.3 Evaluate areas where the levels of transparency may need to be improved.	Information that is unavailable but could help during the use of the proposed XAI has been identified and catalogued for future analysis.	General comments from users suggested that ***some aspects of the system were very intuitive*** and both tools used provide all the information they could need. However, ***the way the information was present in some cases were somewhat obscure could be improved.*** Additionally since the methodology applied by the XAI (solve all of the problems at once) was quite different to how FMP work today (solve problems one by one) – it was identified that the ***provision of aggregated information describing the overall effect of the solutions*** would be advantageous in future – this need has been captured and documented as unavailable information at that moment (the impact of the solution was included but not in aggregated way) and was taken into consideration as an input for the other TAPAS use case of CD&R.	**OK**
	1.4 Propose suitable methods by which the level of understanding and trust	Questionnaires, 'over-the-shoulder' observation and debriefing analysis metrics have been identified to	***Over the shoulder observation*** and the use of ***debriefing*** and ***questionnaires*** at the end of each exercise ***proved to be very useful***, in particular to	**OK**

TAPAS ATFCM Validation Objective	Sub-Focus	Success Criterion	Validation Results	Status
	in the AI automation can be measured	support the necessary measures.	capture how the scores tended to improve as users became more familiar with the platform. In general, levels of trust could be seen to improve as users became more familiar with the tools. This was reflected in the scores which became visibly 'more green' in the later exercises.	
OBJ2: Develop prototype XAI/VA methods for ATM use cases to address transparency at various levels of automation	2.1 Produce customised VA views to support transparency and explanatory information to the human operator at different levels of automation.	VA display tools are able to consume data provided by the XAI component to support interactive drill down views for the human operator	The VA ***display was able to consume data from the XAI*** component and to present a series of visual aids to help users to interrogate information related to Hotspots and solutions being identified by the tool. Detailed capabilities that are ***Sector based and Traffic based allowed users to drill down and interactively*** obtain more detailed information from the VA tools whenever this was required.	**OK**
	2.2 Assess how the VA methods can help enhance operator understanding and trust in AI-based automation	Elements provided in the VA provide clear visual evidence related to the actions being performed by the XAI tools	The ***elements provided in the VA support tool were designed to help users understand the issues*** that had been identified, as well as the reasons why the proposed solutions were selected Users felt that solutions were sometimes slightly difficult to understand. However additional comments from the users suggest that the	**POK**

TAPAS ATFCM Validation Objective	Sub-Focus	Success Criterion	Validation Results	Status
			difference in the paradigm that the XAI uses to create solutions (solve all in one go) contributed to these issues as it was unfamiliar to users who normally solve issues one by one.	
	2.3 Evaluate the effectiveness of the transparency solutions being deployed	Human operators are able to use the visualisation to interrogate the on-going scenario and solutions being considered	Using the ***VA display and features available combined with the FMP client interface, users were able to easily interrogate*** the scenario and investigate solutions being proposed. Additional explanations about how, and why, solutions were selected were provided through the VA sector and traffic exploration features.	**OK**
	2.4 Determine the different needs for transparency at different automation levels	Human operators classify the information being provided and confirm that it is sufficient to explain the decisions being made	At automation level 1 (manual) the users were able to easily classify information being provided (sector load/demand charts, overloads, flight lists etc.). At higher levels of automation, available information could be easily found but users identified missing information which would have helped to improve the explanations being provided	**POK**
	2.5 Evaluate the level of understanding and	Human operators are able to describe what the	In general, using the available features in the FMP client and VA display, ***users were able to***	**OK**

TAPAS ATFCM Validation Objective	Sub-Focus	Success Criterion	Validation Results	Status
	situational awareness of the human as the automation proposes / implements solutions	automation is doing and why solutions have been proposed	***maintain Situational Awareness at all times***, and remained neutral about things being under control. At higher levels of automation, users reported some difficulty to focus on the problem 'as a whole' rather than single problems and were sometimes 'surprised' by unexpected events. This was probably due to the differences of the new operating method used (solve all in one go).	
	2.6 Verify that the human can successfully take over and recover control of the situation if the automation fails for any reason	The human was able to either take over and complete the current task when automation failed,	Not tested during the validation exercise since the activity only addressed nominal situations. This aspect has been partially covered, but not validated, during debriefing sessions.	**Not tested**
	2.7 Ensure that the human is able to identify and resolve any remaining issues at the end of the XAI process, if present.	The human operator was able to identify and to complete any remaining issues that were not successfully solved at the end of the process	Not tested during the validation exercise due to how the XAI module was designed.	**Not tested**
	2.8 Demonstrate how transparency can promote operational and social	The operator confirms that the solutions provided by the XAI were fit for purpose	Users responded either neutrally or slightly negatively when asked whether the system was useful, reliable, accurate and understandable when automation was in place.	**POK**

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TAPAS ATFCM Validation Objective	Sub-Focus	Success Criterion	Validation Results	Status
	acceptance of 'black-box' AI solutions		Information provided to help explain Hotspot identification was reported as being good, but explanations related to solutions were reported as being a little difficult to use in some cases. Scores related to overall confidence in the solutions remained relatively neutral or slightly negative. However, in discussions during the exercises and the debrief sessions, users seemed to be willing to accept that if the solutions that were implemented by the automation were reasonable across all airspace users, then acceptance and trust would be able to be achieved.	
	2.9 Assess shortfalls and areas where transparency can be improved in future solutions	Operational experts identify areas where information was insufficient to support understanding	The ***operational experts were able to review the Hotspots that the XAI identified with relative ease, together with the solutions that were included in the FMP tool and their explanations in the VA display***. However sometimes the information was difficult to understand, some explanation	**POK**

TAPAS ATFCM Validation Objective	Sub-Focus	Success Criterion	Validation Results	Status
			features were no auto explanatory and more focused on how the XAI algorithm worked. In this aspect, users identified that providing information in an 'operational context' would help improve transparency.	
	2.10 Identify opportunities for additional training	Additional training or processes to enhance the ability for the XAI/VA to assist the human in understanding the process at different automation levels has been identified by the team	Following the completion of the various exercises, the analysis team performed a general review of the design, execution and results of the validation scenarios and results. Key points were presented to the TAPAS project partners to provide feedback on Explainability, Tooling and Lessons Learned.	**OK**

2.4.2 CD&R use case

Table 2: Summary of CD&R Validation Exercises Result

TAPAS CD&R Validation Objective	Sub-Focus	Success Criterion	Validation Results	Status
OBJ 1: Identify principles for Transparency of AI-based solutions	1.1 Determine how much additional information is needed at automation levels 2 & 3 to ensure that the human operators can make informed decisions to help solve conflicts identified by the system at various levels of automation.	VA and explanatory support information that is clear and understandable is provided in a short timeframe and the tools provide the required information to allow the user to rapidly understand the situation being managed and context of the proposed solution.	As regular and certified users of the Spanish ATC system, which the SACTA simulator platform replicates, users were highly familiar with the tools and features that the CWP provided. For this reason, it was difficult for them to move away from using those features when analysing predicted conflict situations and their possible solutions during the TAPAS CD&R exercises. Nevertheless, when instructed to use the available information provided in the co-located VA display, users were able to quickly assimilate the information that was provided for a conflict and use the detailed information to review the solutions being proposed. Some features of the display were considered less useful than others. For example, Users indicated that the graphical display of the conflict trajectories provided at the side of the textual information in the VA display was less useful than capabilities already available in the SACTA CWP. When observing the users work at levels 2 and 3, it was clear that they preferred to	**OK**

TAPAS CD&R Validation Objective	Sub-Focus	Success Criterion	Validation Results	Status
			use existing ATC/traffic monitoring features over that view. However, other information that was provided via the co-located display, related to conflict alerts and the proposed actions, was considered very useful and allowed the users to quickly understand the conflict and traffic involved, as well as the solutions that were proposed, even if they did not always agree with the priorities given by the XAI tool. In cases where the users disagreed with the clearances being proposed, or those implemented automatically at level 3, they still tended to accept the solutions if they solved the conflicts – even though the solutions differed from those that they would have applied themselves. However, if the proposed solution only partially solved, or failed to solve the issue, users questioned why those actions had been proposed. In such cases, there was no further information available to explain why those actions had been selected.	

TAPAS CD&R Validation Objective	Sub-Focus	Success Criterion	Validation Results	Status
			In conclusion, most users indicated that due to the often very short lead times for conflicts to be identified, solved and instructions given to traffic, offering more information than was already provided would not necessarily have changed the understanding that they could usually acquire in a very short time due to their own experience and expertise in the domain. Therefore, users generally agreed that the level of information provided was sufficient for their needs in the CD&R use case. Users indicated the need to integrate the VA display information into the SACTA CWP HMI. Having the display located on a smaller screen that was next to the main CWP display required the Radar controller to change from viewing the Radar screen to look at information on the co-located display which was a distraction and could lead to loss of awareness about the evolving traffic conditions in the sector, especially when traffic loads are high and complex. To further evaluate this effect, during some of the later exercises some modifications were included in the CWP to allow the VA-display information to be seen in pop-up dialogues	

TAPAS CD&R Validation Objective	Sub-Focus	Success Criterion	Validation Results	Status
			within the main CWP HMI. When these changes were included in the scenario it was very clear that the controller made more use of the information that was being provided than when it was located on the adjacent display.	
	1.2 Identify when support information is required, what level of detail is needed and how should it be provided in a timely manner.	Key data that can be easily understood by the human has been identified that supports transparency needs and is provided in the required time frame and at an appropriate frequency. Additional information providing more detailed information that can help explain more complex situations and the decisions that were made is available for consultation by the user in an 'on-demand' mode if required	Integration of the XAI and VA information display components was carried out using a publish-subscribe Message Queue solution (RabbitMQ). However, the refresh rates at which key flight plan and track data was shared with the XAI/VA was set at 30-seconds for the experiments. This setting sometimes resulted in delays occurring between a conflict being identified and the related information being provided to the users. Additionally, users needed to wait on some occasions for the information to be updated with the set of proposed resolution action, while on other occasions, the information being displayed was modified or over-written as new or changing conflict situations manifested which caused users to be a little disoriented from time to time. The consequence of these technical issues did have a noticeable impact on the users at times, and they were sometimes waiting for	**OK**

TAPAS CD&R Validation Objective	Sub-Focus	Success Criterion	Validation Results	Status
			information that was expected (based on their own experience/expertise) when it was not already provided. From the perspective of validation objective 1.2, which was looking at both the content and delivery time for key support information, these technical issues provided a good insight into what controllers would need in an eventual operational deployment of such tools. Information was found to be useful and suitably presented in a way that allowed users to quickly comprehend the situation and understand any actions that were being proposed/implemented. However, the delays in presenting information (usually due to the selected data sharing frequency of 30 seconds) did result in some negative effects due to both unexpected delay in the provision of that data as well as sudden updates that caused the user to be a little disoriented at times.	
	1.3 . Evaluate areas where the levels of transparency may need to be improved	Information that is unavailable but could help during the use of the proposed XAI has been	ATC were generally satisfied with information that was made available by the XAI/VA components.	**OK**

TAPAS CD&R Validation Objective	Sub-Focus	Success Criterion	Validation Results	Status
		identified and catalogued for future analysis.	Information provided was easy to use and complemented the expertise of ATCO as well as existing SACTA tool suite.	
	1.4 Propose suitable methods by which the level of understanding and trust in the AI automation can be measured	Questionnaires, 'over-the-shoulder' observation and debriefing analysis metrics have been identified to support the necessary measures.	***Over the shoulder observation*** and the use of ***debriefing*** and ***questionnaires*** at the end of each exercise ***proved to be very useful***, and in general how the scores tended to improve as users became more familiar with the platform.	**OK**
OBJ2: Develop prototype XAI/VA methods for ATM use cases to address transparency at various levels of automation	2.1 Produce customised VA views to support transparency and explanatory information to the human operator at different levels of automation.	VA display tools consumed data provided by the XAI component to support interactive views for the human operator in a timely and concise manner.	In practice, due to the short timeframe between conflicts being identified and the need to implement a suitable and safe clearance to one or more flights, the usefulness of the co-located view was limited. Over the shoulder observation and discussions held during the Level 2 exercises confirmed that the ATCo tended to use the existing functions and features within the SACTA CWP (features that they are highly familiar with already) over any new features that were provided by the VA support display. Furthermore, as the amount and type of information that was able to be provided was somewhat limited, by design to keep it as concise	**OK**

TAPAS CD&R Validation Objective	Sub-Focus	Success Criterion	Validation Results	Status
			as possible, in-depth 'explanatory' information was not available from the VA tool. Furthermore, users indicated that little time is available to use information of this type in a CD&R situation since actions need to be performed and verified rapidly, before moving on to the next task. Other issues were identified in discussions with the users that related to the set-up of the working position. Since the VA support display was located next to the main CWP and was only provided on a small laptop screen, consultation of information on that display resulted in the user losing focus on the main CWP and on-going traffic situation, which in turn could risk a loss of situational awareness or worse. Similarly, the update frequency (30 sec) and lack of clear indication about when data was last refreshed could lead to users being unclear whether the information was up to date (or remaining from a previous situation) and in some cases new data appearing on the display could lead to other information being hidden or potentially lost. A clear improvement in how the information was provided and used by the ATCo was visible when the CWP interface was enhanced to include an additional pop-up window for the VA	

TAPAS CD&R Validation Objective	Sub-Focus	Success Criterion	Validation Results	Status
			information. In this case it was clearly observable that the ATCo made greater use of the information than when it was co-located on the smaller laptop screen. Most, if not all ATCo also indicated that they did not really require the additional graphical view of conflict situations that accompanied conflict details in the VA display. In general, the existing tools in the CWP HMI, combined with the expertise and experience of the ATCo were considered sufficient to understand all of the conflict situations rapidly without the need to consult the additional graphical view, and '*measuring*' tools in the CWP HMI that the ATCo were highly experienced in using were seen as the 'go-to' function when review conflict situations and potential clearances.	
	2.2 Assess how the VA methods can help enhance operator understanding and trust in AI-based automation	Elements provided in the VA provide clear visual evidence related to the actions being performed by the XAI tools	Users had mixed opinions when responding to question about visual evidence for conflict resolution proposals. Low confidence in proposed actions from the automation which did not match how ATCO would have solved the issue themselves influenced some of the answers.	**POK**

TAPAS CD&R Validation Objective	Sub-Focus	Success Criterion	Validation Results	Status
			Questions that were directly related to the information provided about the proposed solution, rather than its quality were well reviewed.	
	2.3 Evaluate the effectiveness of the transparency solutions being deployed	Human operators are able to use the visualisation to interrogate the on-going scenario and solutions being considered	User were able to easily access the information provided in the VA support to understand solutions being proposed and using features in the CWP they could measure the impact/applicability easily.	**OK**
	2.4 Determine the different needs for transparency at different automation levels	Human operators classify the information being provided and confirm that it is sufficient to explain the decisions being made. Optional detailed views are able to support more complex situations and can provide additional detailed understanding in an acceptable timeframe	CD&R users indicated that information provide was sufficient for their needs and no additional data would be necessary to support transparency. In CD&R little/no time is available for drill down actions	**OK**
	2.5 Evaluate the level of understanding and situational awareness of the human as the	Human operators are able to describe what the automation is doing and	Many responses were in agreement or neutral on many questions relating to understanding what the automation was doing/proposing. However, when trying to understand why some	**POK**

TAPAS CD&R Validation Objective	Sub-Focus	Success Criterion	Validation Results	Status
	automation proposes / implements solutions	why solutions have been proposed.	solutions were proposed users were split 40:60 between strongly agreeing and strongly disagreeing suggesting more work is required on this topic.	
	2.6 Verify that the human can successfully take over and recover control of the situation if the automation fails for any reason	The human was able to either take over and complete the current task when automation failed,	Technical issues with the XAI automation resulted in the operator needing to take over control when running at Level 3. However, while ATCO could intervene in most cases, it was not always able to be carried out in a suitable time.	**POK**
	2.7 Ensure that the human is able to identify and resolve any remaining issues at the end of the XAI process, if present.	The human operator was able to identify and to complete any remaining issues that were not successfully solved at the end of the process	For automation level 3 scenarios the XAI only detected some (but not all) of the conflicts. Others that were identified were solved in a less than efficient manner or using 'open loop' manoeuvres (e.g., a heading change) without additional instructions to recover the original plan. Hence the ATCO was required to identify those missing conflicts, enhance some of the solutions and/or include additional clearances to recover the flight plan following a resolution action.	**POK**
	2.8 Demonstrate how transparency can promote operational and social	The operator confirms that the solutions provided by the XAI were fit for purpose	ATCO were able to understand the solutions being proposed using the available information but on some occasions those solutions were not considered suitable to solve the problem.	**POK**

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TAPAS CD&R Validation Objective	Sub-Focus	Success Criterion	Validation Results	Status
	acceptance of 'black-box' AI solutions		Scoring suggests that ATCO confidence in the solutions remained low and this impacted some of the operational acceptance of the automation proposals.	
	2.9 Assess shortfalls and areas where transparency can be improved in future solutions	Operational experts identify areas where information was insufficient to support understanding	In the CD&R scenarios ATC indicated that all required information was already provided. Some issues were reported regarding conformance monitoring, but these were solved once users became familiar with how this feature was supported by the tool. ATC suggested that conformance monitoring in primarily a human task.	**OK**
	2.10 Identify opportunities for additional training	Additional training or processes to enhance the ability for the XAI/VA to assist the human in understanding the process at different automation levels has been identified by the team	Users responded that the system was easy to use and understand with little or no assistance from technical support personnel. Users also indicated that little or no additional training was considered necessary	**OK**

2.5 Technical Deliverables

Reference	Title	Delivery Date[2]	Dissemination Level[3]
	Description		
D1.1	Project Management Plan [1]	07/08/2020	Confidential
This document describes the Project Management Plan (PMP) that TAPAS implemented in order to achieve its research objectives, ensuring that the project scope is fully addressed with an adequate level of quality, in the scheduled time and with the optimal use of the project resources. In addition to the PMP, the progress of the project has been recurrently reported through the complementary documents D1.1.010 Progress Report 1, D1.1.020 Progress Report 2 and D1.1.030 Progress Report 3.			
D1.2	Data Management Plan [5]	30/11/2020	Confidential
This document describes the Data Management Plan (DMP) of TAPAS project. As such, this DMP describes the data management life cycle for all datasets to be collected, processed or generated by TAPAS project during its research activities. It details all data the project collected and generated, how it was exploited or made accessible for verification and re-use, and how it was curated and preserved.			
D2.1	TAPAS Use Cases Description [6]	26/08/2020	Public
This document describes in detail the use cases developed under TAPAS project: (a) from the operational point of view; and (b) from the technological perspective. It also contains the operational context description in which TAPAS use cases are to be developed.			
D2.2	Consolidated Requirements and Functional Roadmap [7]	30/09/2020	Public
This document aims at delivering a consolidated set of functional requirements and the functional roadmap for the allocation of tasks between the human and the machine according to the ATM Master Plan Automation Levels for the TAPAS Operational Use Cases described in TAPAS D2.1. Use Cases Description.			
D3.1	Use Cases Transparency Requirements [8]	31/03/2021	Public
This document describes in detail the set of transparency and explainability requirements implemented in TAPAS project XAI and VA prototypes for the use cases of Air Traffic Flow and Capacity Management (ATFCM), at pre-tactical phase, and the Conflict Detection and Resolution (CD&R), at tactical phase.			
D3.2	Principles for Transparency in AI/ML automation [9]	31/05/2022	Public
This document proposes a set of relevant principles and recommendations to be considered regarding the application of transparent and explainable Artificial Intelligence (AI) in the automation of Air Traffic Flow and Capacity Management (ATFCM) and Conflict Detection and Resolution (CD&R) use cases. It presents some innovative ideas and principles to be considered when automating, at different levels, ATFCM and CD&R use cases using technology based on Explainable AI (XAI) and Visual Analytics (VA). The idea is to be able to use the knowledge presented here and use it as a general guideline and foundations when carrying out the automation of these scenarios, in a more transparent and explainable way for different types of users and practitioners.			

[2] Delivery data of latest edition

[3] Public or Confidential

D4.1	TAPAS Integrated Prototype [11]	30/03/2022	Public
This document provides descriptions of the prototype systems that has been implemented in the context of TAPAS, addressing the requirements of the ATFCM and CD&R use cases. Specifically, the document describes the ATFCM and the CD&R use cases and the specific problem that is considered, together with the data sets that are exploited by the system, per use case. The document describes the overall architecture of the ATFCM and CD&R prototype systems, and the functionality of components, specifying in detail the input and output of each of the components. Finally, the document describes how components are integrated in a prototype system.			
D4.2	Reference of XAI Methods [11]	05/05/2022	Public
This document provides a description of the XAI systems that have been implemented in the context of TAPAS, addressing the requirements of the ATFCM use case and the requirements of the CD&R use case. Specifically, the document describes the ATFCM and CD&R use cases and the specific problems that are considered, the data sets that are exploited by the corresponding systems, the AI/ML methods implemented and the explainability paradigm followed by each method. Experimental results show the quality of solutions provided.			
D4.3	Visualizations and Visual Analytics methods [12]	13/04/2022	Public
This document provides a description of the Visual Analytics components of the prototype systems that have been implemented in the context of TAPAS, addressing the requirements of the two use cases: Air Traffic Flow and Capacity Management (ATFCM) and Conflict Detection and Resolution (CD&R). The document refers to the descriptions of the use cases provided in D4.1 TAPAS Integrated Prototype. The illustrations were created using the example data sets that are exploited within the project. The document describes the overall design of the Visual Analytics components of the ATFCM and CD&R prototype systems, the functionality of the VA modules, and their integration within the TAPAS architecture.			
D5.1	TAPAS Validation Plan [13]	10/05/2021	Public
This document provides a description of the validation activities that were planned within the TAPAS project and includes information for operational scenarios being considered in support of transparency requirements for the use of AI-based automation in ATM. Two distinct validation exercises, one in support of Air Traffic Flow and Capacity Management (ATFCM) and one supporting Conflict Detection and Resolution (CD&R), were performed at the CRIDA facilities in Madrid.			
D5.2	TAPAS Validation Report [14]	11/05/2022	Public
This document the results of the ATFCM and CD&R experiments carried out under the umbrella of TAPAS project. It describes the Several Human-in-the-Loop (HITL) Real Time Simulation (RTS) that were performed for both ATFCM and CD&R use cases involving operational experts to validate eXplainable Artificial Intelligence (XAI) decision support components working in scenarios at different levels of automation (level 1, 2 and 3). The HITL validation experiments were used to extract conclusions and principles for transparency and explainability when deploying automation based on these types of AI tool as described in D3.2 Principles for Transparency in AI/ML automation. Deviations from D5.1 TAPAS VALP, as well as conclusions and recommendations for future activities are also provided.			
D6.1	Exploitation and Dissemination Plan [15]	31/08/2020	Public
This document describes the different exploitation and dissemination activities planned within the TAPAS project and also contains the project communication strategy. Undertaken by TAPAS partners, these activities are identified and developed to guarantee the use and exploitation of TAPAS results and achievements. Dissemination and Exploitation is focused in ensuring that TAPAS outputs are in line with stakeholders' needs and expectations, linking the relevant participation of TAPAS partners with the SESAR Industrial Research and paving the way to further research and exploitation of TAPAS outputs.			
D6.2	Exploitation and Dissemination Report **¡Error! No se encuentra el origen de la referencia.**	31/05/2022	Public

This document describes the different communication, exploitation and dissemination activities that have been achieved within the TAPAS project. Undertaken by TAPAS partners, these activities have been developed to guarantee the use and exploitation of TAPAS results and achievements. Dissemination and Exploitation was focused in ensuring that TAPAS outputs are in line with stakeholders' needs and expectations, linking the relevant participation of TAPAS partners with the SESAR Industrial Research and paving the way to further research and exploitation of TAPAS outputs			
D6.3	Final Project Report [16]	31/05/2022	Public
This document contains the scientific work performed during TAPAS project including an overview of the project, the use cases considered for the validation activities, the technical XAI and VA prototypes developed, and the conclusions and lessons learned throughout the project. It also includes the recommendations for the next R&D phase based on the experience and outcomes obtained about transparency and explainability for AI/ML automation in ATM field.			

Table 3: Project Deliverables

3 Links to SESAR Programme

3.1 Contribution to the ATM Master Plan

TAPAS project considers as basis the different levels of automation as defined in the European ATM Master Plan and adopted by the SESAR programme [21]. Although the objective of TAPAS project was not to change the automation levels defined in the ATM Master Plan, some recommendations on this topic based on the validation exercises performed have been provided.

The latest edition of the European ATM Master Plan introduces an automation model for ATC based on the classic Levels of Automation Taxonomy (LOAT) model used by human performance and safety experts in the SESAR Programme. The SESAR levels of automation model mirrors the six-level model from the Society of Automotive Engineers, ranging from level 0 “no automation” to level 5 “full automation”.

- Level 0 – Low Automation

Automation supports the human operator in information acquisition and exchange and information analysis.

- Level 1 – Decision support

Automation supports the human operator in information acquisition and exchange and information analysis and action selection for some tasks/functions.

- Level 2 – Task Execution Support

Automation supports the human operator in information acquisition and exchange, information analysis, action selection and action implementation for some tasks/functions. Actions are always initiated by Human Operator. Adaptable/adaptive automation concepts support optimal socio-technical system performance.

- Level 3 – Conditional Automation

Automation supports the human operator in information acquisition and exchange, information analysis, action selection and action implementation for most tasks/functions. Automation can initiate actions for some tasks. Adaptable/adaptive automation concepts support optimal socio-technical system performance.

- Level 4 – High Automation

Automation supports the human operator in information acquisition and exchange, information analysis, action selection and action implementation for all tasks/functions. Automation can initiate actions for most tasks. Adaptable/adaptive automation concepts support optimal socio-technical system performance.

- Level 5 – Full Automation

Automation performs all tasks/functions in all conditions. There is no human operator.

The following figure summarises the SESAR Levels of Automation model.

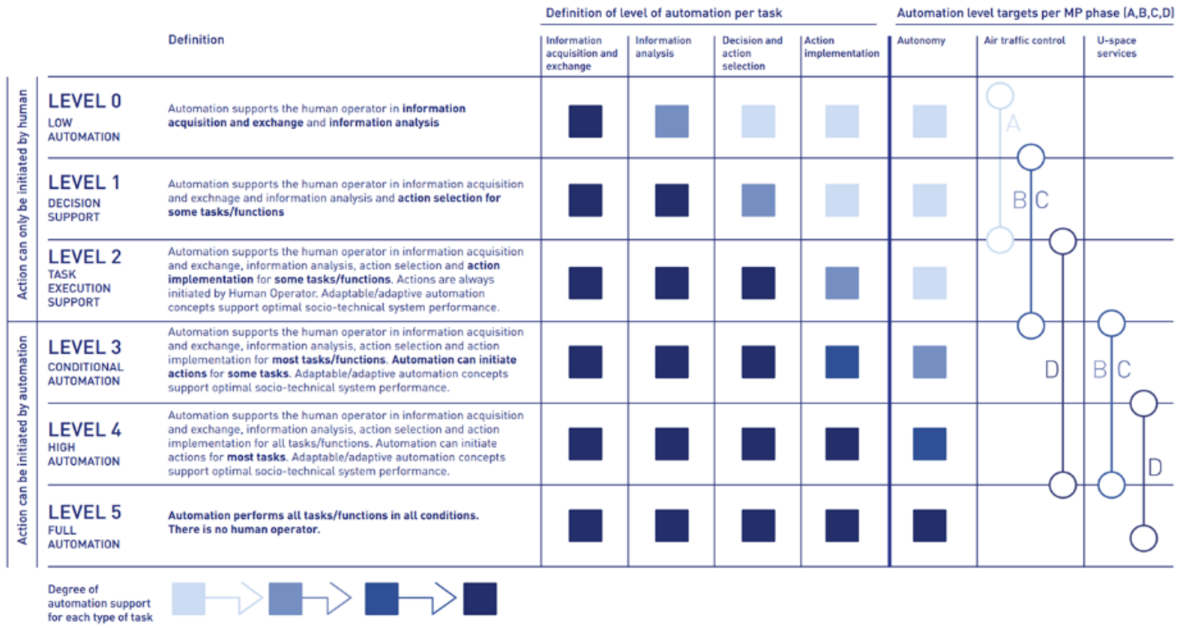

Figure 4: SESAR Levels of Automation Model

The model presented in Figure 4 presents a simplified view of the overall level of automation in each of the ATM Master Plan phases (A to D) in two different areas: ATC and U-space, the second one being out of scope for the TAPAS scenarios. It also highlights the main steps envisioned, considering the progress made in the field of AI/ML which opens the door to a multitude of innovative applications in ATM, some of which are already starting. The goal is not automation per se, but the optimization of the overall ATM system and the maximization human performance and engagement at all times.

In phases A-C, ATC and ATFCM automation developments (both operational cases of TAPAS research) will be focused on increasing the level of system support, while the initiation of actions will always remain with the human. The major breakthrough will happen in phase D, when higher automation levels will remove the human from the loop for selected tasks. Automation in phase D will also enable advanced collaboration paradigms between different human and software ATM agents, with boundaries between ATC and ATFM progressively blurring as automation takes more and more of the tactical ATC tasks.

This roadmap is coherent with the increasing success of AI/ML applications in society, bringing the promise (and expectation) of autonomous systems which will perceive, learn, decide, and -eventually- act on their own. The applicability and acceptance of such systems is, however, currently limited by their lack of explainability of decisions and actions to humans (both operators and other actors such as supervisors or end-users). The ability to explain problems detected and decisions is not purely an ATM need but a global one, for which other initiatives are already ongoing. A remarkable initiative is the US DARPA (Defence Advanced Research Projects Agency), which is progressing in creating an XAI framework addressing a variety of techniques and methods covering the effectiveness-versus-explainability trade space. TAPAS aims at applying and contributing to this state-of-the-art in ATM operational environments, in order to help building principles to facilitate the adoption of these technologies in ATM domain, with their own complexities and features.

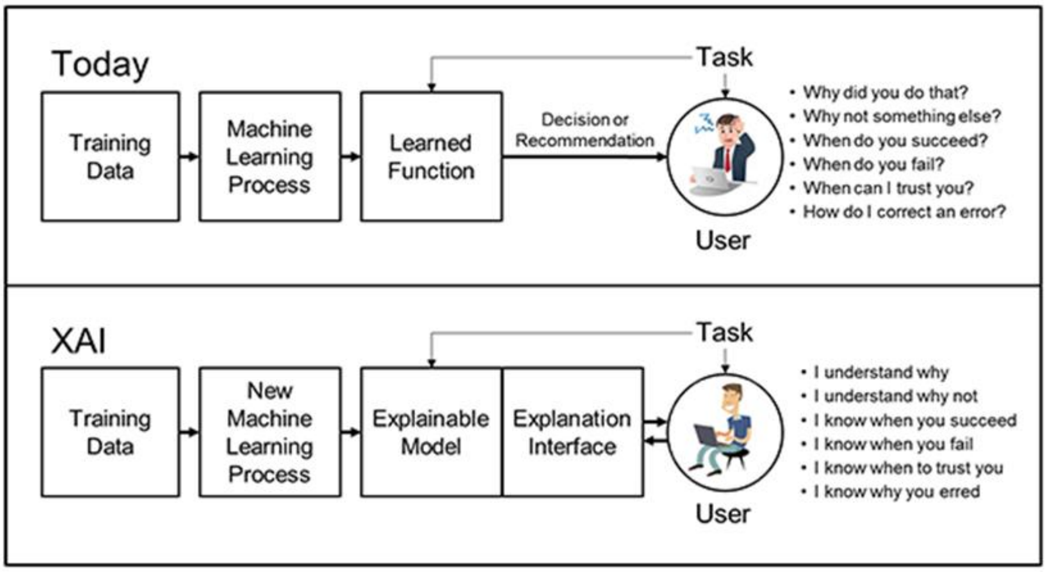

Figure 5: Explainable Artificial Intelligence (XAI)

The SESAR Performance Ambitions are defined in terms of Key Performance Areas. This approach of the SESAR Programme is enshrined in the "SESAR Performance Framework" (SESPF) [23].

One of the KPAs is Capacity, which TAPAS addresses. The increase of automatic processes within the ATCO and FMP work performance leads to a reduction on their workload and functions to be performed. In the case of the ATCO, this reduction of workload is directly related to an increase in airspace capacity.

TAPAS also covers Human Performance (HP) KPA by closely observing the behaviour of ATCOs during validation exercises when faced with different levels of automation. Additionally, the assessment of what the user needs in order to understand and trust the system is included in HP frame. The third KPA covered by TAPAS is Safety. It is important, even though it was not the main objective of the project, to analyse if the solutions proposed by the XAI system would endanger the levels of safety permitted. For these, it is relevant for the user to know the consequences of the resolution actions and evaluate the impact they would have in the rest of the traffic situation.

Finally, and in terms of actual contribution to the ATM Master Plan, TAPAS project proposes the following solution and enablers (Table 4).

- **TAPAS Solution Title**

Capacity on-demand based on eXplainable Artificial Intelligence

- **TAPAS Solution Description**

Artificial Intelligence and Machine Learning are technologies intended to enable higher levels of automation, improving ATM capacity beyond current limitations. Due to the safety-critical nature of ATM domain, the implementations of these technologies should consider explainability and generalisation perspectives, in order to ensure that ATM will remain human-centric and awareness on the system condition and limits of operation are secured. In particular, the solution will use eXplainable Artificial Intelligence techniques (XAI) to provide automated action decision and implementation in

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both ATCFM and ATC conflict detection and resolution functions, for Automation Levels 2 and 3 of ATM Master Plan respectively (action implementation capability being exclusive of level 3). For non-nominal conditions, the system will incorporate a roll-back automated procedure, enabling human override.

The solution targets very high, high and medium complexity en-route sectors, with possible application at network environment.

The benefits in ATM performance will be in terms of en-route capacity and to a lower extent, in predictability and punctuality. The solution aims at having a neutral impact on situational awareness and safety.

Code	Name	Project contribution	Maturity at project start	Maturity at project end
TAPAS – EN01	Automation tool to support FMP tasks	ATFCM use case validation exercises considers the use of XAI and VA methods to support the FMP tasks in relation to hotspots identification and resolution. Automation levels 2 and 3 have been found to be the most applicable to this concept.	TRL-0	TRL1
TAPAS – EN02	Automation tool to reduce ATCO workload	TAPAS developments for CD&R use case aimed at identifying and solving conflicts by the use of XAI and VA methods. The developed system would reduce controller’s workload and, ultimately, increase sector’s capacity. Automation levels 2 and 3 have been found to be the most applicable to this concept.	TRL0	TRL1

Table 4: Project Maturity

The project assessed its Maturity for TRL1 and TRL2 levels. TRL1 (project target maturity level) is considered to be fully achieved, considering the outcome of the Maturity Gate meeting with SESAR JU. In order to identify the gap to achieve TRL2 for potential future research, these criteria have also being assessed and reflected in this document (TRL2 is not considered to be fully achieved by the project, being the result of the assessment TRL2 ongoing). Thereby, the Maturity at project end reflected in table 4 above is TRL1, as targeted at the beginning of the project.

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3.2 Maturity Assessment

Table 5: ER Fund / AO Research Maturity Assessment TRL1

ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
TRL-1.1	Has the ATM problem/challenge/need(s) that innovation would contribute to solve been identified? Where does the problem lie?	Achieved (OK)	The project aims at a transversal objective, which is providing a framework for the development of AI/ML applications in ATM considering Explainability/Transparency needs. This has been achieved successfully by means of a system engineering lifecycle, defining transparency requirements on top of functional/operational ones, validating, and reporting. The results of these activities, considering the benefits and needs of explainability and transparency in higher levels of automation (2 and 3, with particular value in the latest) indicate that the conclusions and guidance provided in this Transparency Framework D3.2 address the identified need.
TRL-1.2	Have the solutions (concepts/capabilities/methodologies) under research been defined and described?	Achieved (OK)	Yes. Both the concept, tools and methodologies that conform the *Transparency Guidelines and the supporting ATFCM and CD&R XAI and Visual Analytics prototypes* have been extensively described in the technical deliverables of the project (see D3.2 [9], D4.1 [10], D4.2 [11], D4.3 [12] and D5.1 [13]). In addition, further results and application of the concepts and technologies are described in detail in the scientific papers published.
TRL-1.3	Have assumptions applicable for the innovative concept/technology been documented?	Achieved (OK)	Yes. All assumptions in the elaboration of *the supporting ATFCM and CD&R XAI and Visual Analytics*

ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
TRL-1.4	Have the research hypothesis been formulated and documented?	Achieved (OK)	*prototypes* have been recorded and described in the technical deliverables of the project (see D4.1 [10], D4.2 [11], D4.3 [12] and D5.1 [13], in particular). The later contains additional hypothesis and assumptions considered during the validation experiments.
TRL-1.5	Do the obtained results from the fundamental research activities suggest innovative solutions (e.g., concepts/methodologies/capabilities? - What are these new concepts/methodologies/capabilities? - Can they be technically implemented?	Achieved (OK)	Yes. The transparency results and experiments clearly indicate the potential to overcome transparency challenges thereby paving the way to AI/ML implementations in ATM. The supporting prototypes have shown the potential to develop capacity on-demand capabilities, able to be technically implemented.

ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
TRL 1.6	Have the potential strengths and benefits of the solution identified and assessed? - Qualitative assessment on potential benefits. This will help orientate future validation activities. Optional: It may be that quantitative information already exists; in which case it should be used.	Achieved (OK)	Yes. TAPAS provides a framework for explainability requirements allowing transversal AI/ML applications to be developed overcoming the explainability barrier. In this sense, the benefits achieved would depend on the specific prototype/OE/SubOE/conditions. However, given the two prototypes developed by the project, a qualitative/quantitative assessment has been done in the most impacting KPAs, mainly capacity. Additionally, a partial HF assessment has been done showing that situational awareness is mostly not impacted (with further analysis to be performed in CD&R level 3). This is a “prerequisite” for Safety neutral impact. In general terms, the project evaluates that the initially expected impact to ATM Master Plan performance Ambitions have been confirmed.

ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
TRL-1.7	Have the potential limitations, weaknesses and constraints of the solution under research been identified and assessed? - The solution under research may be bound by certain constraints, such as time, geographical location, environment, cost of solutions or others. - Qualitative assessment on potential limitations. This will help orientate future validation activities. Optional: It may be that quantitative information already exists; in which case it may be used.	Achieved (OK)	The framework of transparency described in D3.2 [9], together with its underlying methodology, show no limitations in principle depending on local/environmental or cost constraints. Supporting prototypes have been designed considering the need to avoid local limitations and thereby the conclusions are not considered to be biased. From an application perspective, the results have been proved for Automation levels 2 and 3 (as described in the ATM Master Plan). Higher values can't be considered as addressed.
TRL-1.8	Do fundamental research results show contribution to the Programme strategic objectives e.g., performance ambitions identified at the ATM MP Level?	Achieved (OK)	The current SESAR Performance Ambitions are not directly addressed by TAPAS explainability framework, as it addresses methodologies rather than Operational Improvements. However, TAPAS results are considered as an enabler for AI/ML application that help to achieve ATM MP Ambitions, in particular in terms of Capacity. In any case, as described in TRL1.7, the assessment and analysis performed with the developed prototype, the project considers that the initially expected impact to ATM Master Plan performance Ambitions have been confirmed.

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ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
TRL-1.9	Have stakeholders been identified, consulted and involved in the assessment of the results?. Has their feedback been documented in project deliverables? Have stakeholders shown their interest on the proposed solution?	Achieved (OK)	Several meetings with TAPAS Advisory Board (documented in TAPAS Project Management Plan) have been held during the project lifecycle to integrate their feedback onto project deliverables. Potential applications of TAPAS solution have been identified by the AB. Complementarily, ENAIRE has been informed on the results and they will be taken into account in short-term operational developments (ongoing work).
TRL-1.10	Have initial scientific observations been communicated and disseminated (e.g., technical reports/journals/conference papers)?	Achieved (OK)	Yes. On the one hand, TAPAS has counted on a high-level Advisory Board for which 4 workshops presenting and discussing results have been organized. On top of this, the project has presented, with acceptance, peer-reviewed posters, conferences and journal papers (Q1).
TRL-1.11	Are recommendations for further scientific research documented?	Achieved (OK)	Yes. Key deliverables (see D3.2 [9], D4.1 [10], D4.2 [11], D4.3 [12] and D5.2 [14], together with the Final Project Results Report, D6.3) include recommendations on further research activities to keep evolving the concept.

Table 6: ER Fund / AO Research Maturity Assessment TRL2

ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
OPS.ER.1	Has a potential new idea or concept been identified that employs a new scientific fact/principle?	Achieved (OK)	Yes. The project has developed a Transparency framework enabling the application of AI/ML technologies in ATM applications. In particular, XAI techniques has been applied to two different

ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
			prototypes – unprecedented in ATM applications.
OPS.ER.2	Have the basic scientific principles underpinning the idea/concept been identified?	Achieved (OK)	Yes. The technology foundations and methodologies are described in the key deliverables (see D3.2 [9], D4.1 [10], D4.2 [11], D4.3 [12])
OPS.ER.3	Does the analysis of the "state of the art" show that the new concept / idea / technology fills a need?	Achieved (OK)	Yes. The need was identified since the proposal, and experiments, activities and research have confirmed the need to develop guidance on explainability/transparency features
OPS.ER.4	Has the new concept or technology been described with sufficient detail? Does it describe a potentially useful new capability for the ATM system?	Achieved (OK)	Yes. The technology foundations and methodologies are described in the key deliverables (see D3.2 [9], D4.1 [10], D4.2 [11], D4.3 [12])
OPS.ER.5	Are the relevant stakeholders and their expectations identified?	Achieved (OK)	Yes. Exploitation, Communication and Dissemination plan identifies them
OPS.ER.6	Are there potential (sub)operating environments identified where, if deployed, the concept would bring performance benefits?	Not Applicable	On the one hand, the explainability framework provided by the project paves the way to AI/ML applications in all OE/subOE in principle, with no identified limitations. In this direction, the criteria is considered to be achieved. On the other, the two developed prototypes would mainly impact En-route environment
SYS.ER.1	Has the potential impact of the concept/idea on the target architecture been identified and described?	Not Applicable	The project aims at a transversal objective, which is providing a framework for the development of AI/ML applications in ATM considering

ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
			Explainability/Transparency needs. This has been achieved successfully by means of a system engineering lifecycle, defining transparency requirements on top of functional/operational ones, validating, and reporting. Thereby, is the application in a specific module which requires an integration on the architecture. The supporting prototypes, as an example, describe their integration in the existing ATM architecture
SYS.ER.2	Have automation needs e.g., tools required to support the concept/idea been identified and described?	Achieved (OK)	Yes. Assumptions are recorded also in terms of automation needs (mostly in terms of data provision). They are described in D5.1 [13] for both use cases.
SYS.ER.3	Have initial functional requirements been documented?	Achieved (OK)	Yes. Functional and transparency requirements are described, respectively in D2.2 [7] and D3.2 [9].
PER.ER.1	Has a feasibility study been performed to confirm the potential feasibility and usefulness of the new concept / idea / Technology being identified?	Achieved (OK)	Yes. The transparency guidance framework has been evaluated in two prototypes involving XAI technologies: ATFCM and CD&R
PER.ER.2	Is there a documented analysis and description of the benefit and costs mechanisms and associated Influence Factors?	Not achieved	TAPAS addresses a transversal transparency/explainability framework, thereby its benefits are indirect on depending on the actual AI/ML implementation. With respect to the two prototypes, due to its "demonstrator" nature they are not designed as fully performant tools and a full quantitative performance assessment was not conducted. Some benefits were estimated in the VALR, though.

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ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
PER.ER.3	Has an initial cost / benefit assessment been produced?	Not achieved	Same as PER.ER.2
PER.ER.4	Have the conceptual safety benefits and risks been identified?	Not achieved	Same as PER.ER.2
PER.ER.5	Have the conceptual security risks and benefits been identified?	Not achieved	Same as PER.ER.2
PER.ER.6	Have the conceptual environmental impacts been identified?	Not achieved	Same as PER.ER.2
PER.ER.7	Have the conceptual Human Performance aspects been identified?	Partial Achievement	Questionnaires have been used enabling an initial HF assessment, although not complete for full SESAR standards.
VAL.ER.1	Are the relevant R&D needs identified and documented? Note: R&D needs state major questions and open issues to be addressed during the development, verification and validation of a SESAR Solution. They justify the need to continue research on a given SESAR Solution once Exploratory Research activities have been completed, and the definition of validation exercises and validation objectives in following maturity phases.	Achieved (OK)	Yes. Key deliverables (see D3.2, D4.1, D4.2, D4.3 and D5.2, together with the Final Project Results Report, D6.3) identify the addressed R&D needs, and at the same time include recommendations on further research activities to keep evolving the concept, including future R&D needs. The focus is more on the transversal output from TAPAS project than in the formulation as a solution, although some challenges (de-skilling, back-to-normal) are identified and described.
TRA.ER.1	Are there recommendations proposed for completing V1 (TRL-2)?	Achieved (OK)	Yes. The recommendations and conclusions provided, as well as the SESAR Solution description (SOL-TAPAS), describe the recommendations to be achieved to progress in higher maturity levels.

4 Conclusion and Lessons Learned

4.1 Conclusions

The main general conclusion of TAPAS project relates to the achievement of all the research objectives, as stated in section 2.2, in accordance with their expressed success criteria:

Table 7: Achievement of Project objectives

ID	Research Objective	Success Criterion	Obtained Result
OBJ1	**Identification of principles and criteria for AI/ML transparency/explainability in ATM domain scenarios**, based on the two operational cases considered and with the target to identify transparency requirements for AI/ML methods in general, limiting domain-specific results.	The roadmap for function distribution per automation level in each operational scenario is set	Achieved (OK). Deliverable D2.2 Consolidated Requirements and Functional Roadmap described these roadmaps in detail
		The criteria for explainability of AI/ML methods are identified and experimentally verified for the different levels of automation being considered, and for the different actors involved (as explainability might not only be needed for system operators). This will include recommendations for certification of such functionalities.	Achieved (OK). Deliverable D3.1 Use Cases Transparency Requirements included the necessary requirements and deliverable D3.2 Principles for Transparency in AI/ML automation, together with D5.2 Validation Report, described both the compliance with the criteria and the general recommendations and conclusions.
OBJ2	**Selection and development of suitable and explainable AI/ML methods in the operational cases** identified, to fit the needs of transparency as expressed in the explainability criteria developed for each automation level and according to actors' needs. Given the early Technology Readiness Level (TRL) of this project (pre-TRL 1), these prototypes would be focused on testing purposes.	The identified AI/ML based functionalities are implemented in the testing environments allowing evaluation of their explainability versus effectiveness in practice.	Achieved (OK). Deliverable D4.1 TAPAS Integrated Prototype describes the implemented prototypes, while D5.2 Validation Report illustrates the results obtained with their use during validation activities
		The different techniques used or explored can be categorized in terms of general suitability (combining effectiveness and	Achieved (OK). Deliverable D4.2 Reference of XAI Methods provides these

ID	Research Objective	Success Criterion	Obtained Result
		explainability) for the operational cases considered.	description, together with further details on the datasets used, technical details on the techniques implementations, and results on the quality of the solutions provided.

In a more detailed perspective, the conclusions obtained from the validation exercises carried out for ATFCM and CD&R use cases are mainly stated in D3.2 Principles for Transparency in AI/ML automation [9] through the objective assessment of the transparency requirements identified in [9] and D5.2 Validation Report [14]. The most remarkable aspects of such conclusions are:

- **Rather than having explanations the user needs to trust the system[4].** Through the constant use of the system, especially during the training phase, the human actor was able to develop trust in the system through how it performed and the solutions it was providing. For example, a booster for stimulating the human understanding and building of trust is to see the impact of the solution implemented/proposed by the system before making decisions. This seems to be more valuable than the current explanations provided by the support tools by the users.

- **Confidence and trust can be volatile[5].** Developing trust and confidence in a XAI system does take a long time and also relies on that system providing reliable solutions that the user accepts as being a valid response to a problem. In the event where something subsequently fails badly, even after trust has been achieved, that confidence in the system can be lost very rapidly and rebuilding it can be hard. This is especially critical in the CD&R domain, and therefore heavy focus on the reliability and suitability of solutions being proposed must be paid.

- **Different levels of explainability are necessary according to the time horizon considered[6].**

    - **During the operation.** Users do not need to see all information or explanations related to the proposed solutions by the XAI algorithm (it also requires a time that they generally do not have).

    - **During training.** This is the phase were more explanations on the algorithm and solutions provided by the AI are needed and appreciated by the user, but once the approach being used was understood, users did not really interrogate this information further.

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[4] Principle “On Trust Building through Explanations” on section 7.2.2 in D3.2
[5] Principle “Trust Volatility” on section 7.2.2 in D3.2
[6] Principles “Ongoing actions define Transparency Needs” and “Off-line and On-line transparency” on section 7.2.1 in D3.2

- **Complexity of the solutions limits the capacity of the human to understand the explanations in real time[7].** Although the explanations are provided, in cases where the solution is too complex the human will have neither the time nor the ability to understand the solutions. However, as previously stated, more than having explanations the user wants to see the impact of the solution implemented/proposed by the system, which they previously got to trust in the training phase.

- **When multiple solutions are possible for the same issue, clear ranking of the solutions from best to worst is of great value[8]** – this is particularly important in time-constrained, safety critical situations typically seen in the CD&R scenarios.

- **When actions are being automatically performed by the XAI system, the status of those actions should be clearly indicated[9]** - e.g., whether those actions are pending, in progress or completed.

- **For the safety critical use case of the CD&R, automation level 3 does not seem feasible to implement[10]**. As an example, performing a monitoring task alone may result in ATCO loss of expertise in the controlling tasks and whenever the XAI fails (even though it will supposedly work well most of the times) the ATCOs will not have the capability to recover control in complex situations in a safe manner.

- **The traceability of explanations is key for transparency[11].** The user needs, not only to see the final explanation of the solutions but have a clear traceability of the elements related to each measure/solution. In particular, in ATFCM scenarios they prefer to see aggregated information, but they appreciate the possibility of following the thread of certain solution down to the level of the flights to which it is related. This gives a clear transparency to the solutions or explanations provided, making it easier for the user to build trust in the system.

- **In CD&R scenarios the importance lies on providing solutions that work well and are accurate, rather than focusing on explanations[12]**. Users consider that little or no additional explanatory information is needed since the combination of information already provided (usually linked to conflict characteristics) combined with a prioritisation of choices is sufficient to allow them to rapidly understand the proposals being made/implemented and the consequences of those actions.

- **Automation factors that degrade trust in CD&R scenarios[13].** Different aspects, such as a combination of unrealistic (from the human way of thinking perspective) solutions, or solutions that may have led to more complex issues further downstream, along with the lack of additional actions that are also considered to be an integral and necessary part of the

[7] Principle “Information Assimilation and Understanding” on section 7.2.1 in D3.2
[8] Recommendation on section 7.3 in D3.2
[9] Recommendation on section 7.3 in D3.2
[10] Principle “Automation Levels and Situational Awareness” on section 7.2.4 in D3.2
[11] Principle “General Structure of Explanations” on section 7.2.1 in D3.2
[12] Conclusion on section 6.3.1 (Explainability/concept maturity) in D3.2
[13] Conclusion on section 6.3.3 (Trust and confidence building) in D3.2

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conflict resolution (resumption of flight plan) process may contribute to a reduction in trust and confidence in the automation.

4.2 Technical Lessons Learned

Validation exercises performed also led to certain technical lessons learned explained in detail in D3.2 Principles for Transparency in AI/ML automation [9] and D5.2 Validation Report [14]. These lessons can be summarized as follows:

- **Algorithms must prove unbiasedness to allow higher levels of automation in ATM.** The algorithms cannot systematically benefit or penalise the same airline, type of aircraft, route, etc. They must be impartial to guarantee fairness among all the airspace users. Even if such a bias is not explicitly implemented, it must be ensured and proved that the algorithm has no unintentional bias. This represents an inherent risk when using systems based on learning, therefore corrective actions during the training process are necessary to avoid them.

- **Automation can play an important role in fairness increase**. In CD&R scenarios, when an ATCO decides to implement a conflict resolution action, it is known that this may not always be the fairest solution. In order to implement the fairer actions, the ATCO might need to communicate to more than one pilot in some occasions, and this certainly takes time that is not available. Machines, though, could look for solutions that are fairer, even when these involve to multiple pilots. For instance, an adequate automation is potentially able to issue instructions to multiple pilots at the same time, minimizing the required time, thus increasing fairness at the same time.

- **Additional actions that are also considered to be an integral and necessary part of the conflict resolution process, such as recovery of the original flight plan, should be included in the resolution.** Additionally, other aspects of the conflict resolution process such as directional flight level strategies, aircraft types/performance characteristics, proximity to departure/arrival airport etc., were not necessarily incorporated into the automation tool. Hence some of the resolutions actions that were proposed were inconsistent with actual practices in the sectors that were simulated, which could lead to a reduction in confidence in the tool.

    - **Tools must be closely integrated.** This means that they must consume the same real-time information to ensure data consistency. **In ATFCM.** In the actual operating environment and tactical/pre-tactical phase, the developed tools need to consider multiple parameters so that the proposed solution is efficient and feasible. If the tools are not properly integrated, the human is not able to select a subset of proposed solutions, implement them using a what-if simulation to obtain a partial solution, then re-consult the XAI to evaluate the resulting situation.

    - **In CD&R.** In these scenarios is important that tools are closely integrated, with a focus on information being exchanged using messaging protocols to allow the XAI to identify conflicts, make decisions and develop solutions in an interoperable manner. This allows the tools to be used in a realistic, real-time mode and to respond to unexpected conflicts which may have resulted due to other ATC or flight deck actions.

4.3 Organisational/Non-technical Lessons Learned

In parallel to the technical lessons expressed above, the project was able to identify a set of general lessons learnt, transversal to many areas and based on the experience during the project (which should be considered also in terms of a pandemic scenario where face-to-face meetings where very restricted or even impossible). These organisational lessons learnt are the following:

The participation of ATCOs/operational staff should include the necessary level of expertise and not limit to validation activities. The two use cases, providing two round of validation experiments, proved that the engagement of operational staff in the prototype requirements and design, even at a high level where general recommendations are given, provides better results than a participation limited to validation experiments, also in terms of system understanding and trust. TAPAS second round of experiments included an enlarged interaction of ATCOs with project member at an earlier stage, even to understand the use case – this, together with the previous iteration, resulted in a more fruitful exchange during the validations as the learning process was more natural and intuitive of ATCOs is also a fundamental factor here.

The project was privileged to count on very expert operational staff, including training managers, but the opportunity to count on ATCO students was discussed at a given time: analysis and experience recommended to prevent any potential bias due to larger number of less skilled participants in favour of more expert views. Given the valuable exchanges achieved, this is considered to be a right decision and the participation of skilled ATCOs, even in a reduced number, is considered preferrable. This has been considered particularly relevant in the pandemic context where personal sessions with ATCOs where limited, and definitively should be a factor to be taken into account in activities where Human Factors play a fundamental role.

- **The composition of the Advisory Board, particularly in lower TRL projects, may have a significant influence in the project results**. The less mature of these less mature concepts may result in a divergence or loss of operational context and potential future applications. The Advisory Board from TAPAS was highly qualified and its opinion was seek in critical design decisions points. Its feedback was particularly relevant between the first and second use case, where indications of the kind of evidence to be proposed in order to maximise potential external use of results was given. The project is grateful and acknowledges the significant contribution of the Advisory Board, and recommends to give the necessary attention to the configuration of this body. Again, this was particularly relevant in a pandemic context, where interactions between parts have been more difficult and some recommentations from the board may have been lost.

4.4 Plan for next R&D phase (Next steps)

Artificial Intelligence and Machine Learning are technologies intended to enable higher levels of automation, improving ATM capacity beyond current limitations. Due to the safety-critical nature of ATM domain, the implementations of these technologies should consider explainability and generalisation perspectives, in order to ensure that ATM will remain human-centric and awareness on the system condition and limits of operation are secured.

This project has implemented XAI prototypes which have been successfully used by ATCOs, as a mean to building a framework for future applications in levels 2 and 3 of Automation according to ATM Master Plan. The natural follow up, still in Exploratory Research activities, would be to apply the adquired knowledge into building more mature prototypes which can explore in detail the intended applications (i.e. the reasonable limits of capacity on-demand, in particular in relationship to other KPAS, while at the same time further tackle the new challenges arising for the project research (such as back-to-normal automated mode. In the project vision, he next R&D phase should transform the transversal knowledge adquired into more advanced prototypes which use eXplainable Artificial Intelligence techniques (XAI) in a more focused way, to provide automated action decision and implementation oriented to strategic/pre-tactical planning enabling capacity on-demand that may exceed existing limitations. The objective, as mentioned, would be to demonstrate the and quantify the benefits of using AI which is at same time transparent -and thereby able to be used in ATM- in an operational context providing flexible, scalable and resilient capacity based on higher levels of automation (2 and 3). The exploration of more advanced levels of automation is considered too uncertain due to the probable required changes in the concept of operations and regulatory framework, which require a certain base of levels 2 and 3 XAI applications.

While enhanced and more performant prototypes can be considered for the use cases independently (even for others), the progressive progression to higher levels of automation may allow a more integrated exploratory research where both (and joint) ATCFM and pre-tactical ATC conflict detection and resolution functions are developed, for Automation Levels 2 and 3 of ATM Master Plan respectively (action implementation capability being exclusive of level 3). This goes deeper in the direction of teaming up the Human and the Machine, more than a “mere” distribution of roles and functions: there are existing synergies which may enable unprecedented levels of ATM performance when properly combining both parts. All the above is considered as Exploratory Research, more application oriented than fundamental, of course. In this direction, early applications in mature Industrial Research solutions may be explored, although this is not recommended in less mature IR solutions where the concept definition itself may influence and impact the behaviour of the XAI; an stable system (so able to learn from it) would be ideal for this line of research.

On the other hand, it is recommended that, given the transversal nature of the transparency guidelines developed, adequate dissemination not just at project level is given. Any Industrial Research or even Exploratory Research activity planning to use AI/ML technologies may be made aware of these results in order to facilitate future uptake of its future results.

Last, the project touched upon certification and testing aspects, although they were not evaluated in such detail as the operational one. A parallel future research would consider these aspects, in order to avoid any future non-technical barriers.

4.5 Recommendations

The research conducted by the project has given the initial steps in a field of technology that is a key enabler for the uptake of AI/ML technologies in a domain as sensitive as Air Traffic Management. Even if the outcomes are valid, the deployment of such technologies in ATM will face barriers in their effective adoption that should be mitigated with the follow-up research beforehand, in order to avoid dead times and regulatory/labour/social barriers which are as critical, if not more, than technical.

The project recommends that the line of research focused on Transparency and Explainability in AI/ML application in ATM is continued by deeper exploring the ways in which the human and the machine will interact and, in an ideal case, team up. This potential research, based on the foundations of explainability and trust, is necessary to overcome the second round of challenges, related to the synergies of the joint operations between the human and the machine, moving from the “human-in-the-loop” concept to the “human-in-the-team” one.

5 Communication, Dissemination and Exploitation

5.1 Communication, Dissemination and Exploitation objectives

D6.1 (Communication, Dissemination and Exploitation Plan) [15], submitted and approved by SJU, detailed the communication and dissemination plan, including exploitation matters, for TAPAS project. Additionally, it identified a focal contact for communication purposes, together with three project key messages and a short description to be broadcasted in different media with the aim at making the project understandable at a first glance.

On the other hand, the deliverable set the Communication, Dissemination and Exploitation objectives, which are reproduced below. With them, the intended communication, dissemination, and exploitation strategy was described, in order to reach the established goals. This strategy included the communication target audiences, communications channels and dissemination means (including the project's website, the social media, etc), the open-to scientific publications, and the strategy to engage different stakeholders. Finally, a detailed communication and dissemination plan of activities was presented.

5.1.1 Communication objectives and strategy

The goal of the Communication Plan is to promote the project and its results. For this purpose, the plan presented in this section defines clear objectives and sets out a specific strategic planning for the communication activities in a strategic and effective manner.

The established communication objectives were:

- To optimise the information flow among the project members and organize an efficient communication between involved stakeholders;
- To broadcast the project to the affected target audiences and main stakeholders, including other Exploratory Research and SESAR2020 projects;
- To inform and communicate the project results to the interested policy body.

The communication strategy supported the exploitation of project results, focusing on the coordination of the outreach and dissemination activities necessary to achieve the project exploitation targets and promoting the work done during the project by using appropriate and useful tools, methods and channels.

5.1.2 Dissemination objectives and strategy

The dissemination of scientific discoveries is one of the inherent activities of TAPAS project, whose results aimed at being general principles for deploying AI/ML automation in ATM.

Regarding the dissemination objectives, they have changed as the project progressed. At the beginning of the project, dissemination focused specially on catching the interest of target stakeholders and getting their feedback to ensure that their inputs feed TAPAS activities. Later on, dissemination priorities gradually moved towards the publication of results to ensure their further exploitation.

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5.1.3 Exploitation strategy and objectives

The exploitation goals are linked with the utilization of TAPAS' results in further research activities and in developing enhanced prototypes that will improve the ones developed within the scope of the project.

The main results of TAPAS achieved during the project have been:

1. Principles for transparency in AI/ML automation in ATM domain
2. Reference of XAI methods applicable in ATM domain
3. Reference on visualization in Visual analytics methods in ATM domain.
4. ATFCM and CDR prototype based on XAI and VA techniques

As established in CDE Plan **¡Error! No se encuentra el origen de la referencia.**, the exploitation strategy was divided into three main areas:

1. Outputs. It has taken into account the basic principles and the formulated Technology Concept, as well as general guidelines for further applications.
2. Documents. Proper technical reports (both intermediate and final deliverables) and research papers to make available to the community the outputs of the project have been generated.
3. Users. This area focused on the exchange of information of the TAPAS achievements among the projects and the potential users of the results. In this way, it has been very important for this area, to take advantage of the Advisory Board.

Finally, CDE plan also described the main exploitation objectives as: use of TAPAS outcomes beyond TAPAS project lifecycle in other different projects as a baseline for further developments in automation and application of XAI/ML and VA techniques and use of Principles for transparency in AI/ML automation in ATM domain to be used by the industry when developing new automated systems.

5.2 Communication, Dissemination and Exploitation results

At the end of the research stage, the results of the communication, dissemination and exploitation actions carried out were described in D6.2 Exploitation and Dissemination Report [16], submitted and approved by SJU. A summary of these actions is included in the following subsections.

Different communications activities have been conducted during the project, in alignment with the aforementioned CDE plan and strategy described above. They are listed below, and can be found in detail in the referred report.

5.2.1 List of Communication Channels and Activities

Channel	Link
TAPAS Website	https://tapas-atm.eu/

TAPAS Twitter	https://twitter.com/TAPAS_SESAR_ER4
TAPAS LinkedIn	https://es.linkedin.com/in/tapas-project-744b3b208
SESAR newsletter	https://www.sesarju.eu/news/explainable-ai-key-unlocking-potential-automation-air-traffic-management

Table 8. Channels list and links.

As an indication of the effectiveness of these channels, the TAPAS twitter account made 20 publications, which were echoed by related stakeholders such as ENAIRE and SESAR JU, helping to maximise visibility. Respectively, the project has published 7 LinkedIn posts, referring to some of the key milestones achieved. One SESAR newsletter was published.

5.2.2 List of Dissemination Activities.

Following the dissemination plan with the objective of maximising scientific impact and scientific excellence, different dissemination activities have been conducted during the project. See Table 9.

Activity	Brief Description
SESAR Innovation Days 2020.	Poster and video.
ER4 Automation Workshop. First Edition.	Presentation of TAPAS Project.
ER4 Automation Workshop. Second Edition.	Organization of the Workshop and presentation of TAPAS Project.
Advisory Board Workshops.	Organization of the Workshops and presentation of the main outcomes to the AB experts.
Digital Academy Webinar.	Participation in the Digital Academy Webinars organised by SESAR.

Table 9. List of dissemination activities.

As an example of the effectiveness of the dissemination activities, the SESAR Digital Academy Webinar where TAPAS presented its results had a sustained attendance of over 200 persons, with more than 300 registered. The satisfaction survey conducted at the end show great interest and valued positively the presentation made.

5.2.3 List of Exploitation Activities.

Following the dissemination plan with the objective of maximising scientific impact and scientific excellence, different dissemination activities have been conducted during the project. See Table 9. Together with these, some additional papers are completing their acceptance process at the closure of this report.

Activity	Brief Description

XRL Survey.	**Explainable Deep Reinforcement Learning: State of the Art and Challenges**. George A. Vouros, University of Piraeus, Greece.
XAI at ATFCM	**Explaining Deep Reinforcement Learning Decisions in Complex Multi Agent Settings: Towards Enabling Automation in Air Traffic Flow Management.** Theocharis Kravaris et all.
VA paper.	**Supporting Visual Exploration of Iterative Job Scheduling.** Gennady and Natalia Andrienko et all.

Table 10. List of exploitation activities.

6 References

6.1 Project Deliverables

[1] TAPAS, Project Management Plan, D1.1, Ed. 00.01.01, 07/08/2020

[2] TAPAS, Progress Report 1, D1.1.010, Ed. 00.01.01, 26/11/2020

[3] TAPAS, Progress Report 2, D1.1.020, Ed. 00.01.00, 11/04/2022

[4] TAPAS, Progress Report 3, D1.1.030, Ed. 00.01.00, 01/06/2022

[5] TAPAS, Data Management Plan, D1.2, Ed. 00.01.01, 30/11/2020

[6] TAPAS, Use Cases Description, D2.1, Ed. 00.01.01, 26/08/2020 (Download)

[7] TAPAS, Consolidated Requirements and Functional Roadmap, D2.2, Ed. 00.02.00, 30/09/2020 (Download)

[8] TAPAS, Use Cases Transparency Requirements, D3.1, Ed. 00.00.03, 31/03/2021 (Download)

[9] TAPAS, Principles for Transparency in AI/ML automation, D3.2, Ed. 00.02.00, 31/05/2022 (Download)

[10] TAPAS, TAPAS Integrated Prototype, D4.1, Ed. 00.04.00, 30/03/2022 (Download)

[11] TAPAS, Reference for XAI Methods, D4.2, Ed. 00.02.00, 05/05/2022 (Download)

[12] TAPAS, Visualizations and Visual Analytics methods, D4.3, Ed. 00.02.02, 13/04/2022 (Download)

[13] TAPAS, Validation Plan, D5.1, Ed. 00.02.02, 10/05/2021 (Download)

[14] TAPAS, Validation Report, D5.2, Ed. 00.02.00, 11/05/2022 (Download)

[15] TAPAS, Exploitation and Dissemination Plan, D6.1, Ed. 00.01.03, 31/08/2020 (Download)

[16] TAPAS, Exploitation and Dissemination Report, D6.2, Ed. 00.01.00, 31/05/2022

6.2 Project Publications

[17] **G. Andrienko, N. Andrienko et al**., "Supporting Visual Exploration of Iterative Job Scheduling," in IEEE Computer Graphics and Applications, doi: 10.1109/MCG.2022.3163437. (see link)

[18] **T. Kravaris, K. Lentzos, G. Santipantakis, G.A. Vouros**, "Explaining deep reinforcement learning decisions in complex multi agent settings: towards enabling automation in air traffic flow management" in Applied Intelligence Journal.

[19] **G.A. Vouros, "**Explainable Deep Reinforcement Learning: State of the Art and Challenges" in the Association for Computing Machinery (ACM) (see link).

6.3 Other

[20] Project Execution Guidelines for SESAR Exploratory Research, Edition 01.00.00, 08/02/2016

[21] European ATM Master Plan

[22] 'Ethics Guidelines for Trustworthy AI'. High Level Expert Group on AI. European Commission. April 2019

[23] SESAR JOINT UNDERTAKING (2022). D4.4 PJ19-W2: Performance Framework. Edition 00.01.00 (Under review). Available at S3JU Stellar Platform.

[24] 18-02A SPR-INTEROP/OSED Trajectory Management for V1 - Part I, Edition 00.01.00, 2019

[25] SESAR 2020 Concept Of Operations Edition 2019 Edition 01.00.00.

[26] PJ06-D2_1_030 V3 SPR INTEROP OSED Final Version - Part I Edition 00.03.02, 2019.

[27] SESAR Solution 08.01 SPR-INTEROP-OSED for V2 - Part I Edition 02.00.03, 2019.

[28] SESAR Solution PJ.10-01b (Flight Centric ATC) FINAL SPR-INTEROP/OSED for V2 - Part I, Edition 00.04.00, 2019.

Appendix A

A.1 Acronyms and Terminology

Term	Definition
AI	Artificial Intelligence
ANSP	Air Navigation Service Provider
ATC	Air Traffic Control
ATCo	Air Traffic Controller
ATFCM	Air Traffic Flow and Capacity Management
ATM	Air Traffic Management
CD&R	Conflict Detection and Resolution
CWP	Controller Working Position
DCB	Demand and Capacity Balance
DDR2	Demand Data Repository
DST	Decision Support Tool
FMP	Flow Management Position
HITL	Human In The Loop
HMI	Human Machine Interface
INNOVE	INnovative Network Operations Validation Environment
iTEC	Interoperability Through European Collaboration
KPI	Key Performance Indicator
LTM	Local Traffic Manager
ML	Machine Learning
NM	Network Manager
OCVM	Operational Concept Validation Methodology
SESAR	Single European Sky ATM Research
SJU	SESAR Joint Undertaking
TAPAS	Towards an Automated and Explainable ATM System

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TBO	Trajectory Based Operations
TRL	Technology Readiness Level
VA	Visual Analytics
VALP	Validation Plan
VALR	Validation Report
XAI	Explainable AI

Table 11: Acronyms and terminology