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Copyright Statement

TAPAS

TOWARDS AN AUTOMATED AND EXPLAINABLE ATM SYSTEM

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Abstract

This document provides a description of the validation activities that are 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), will be performed at the CRIDA facilities in Madrid.

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1 Executive Summary

The TAPAS research is looking to demonstrate how, using *explainability* and *transparency* components, Artificial Intelligence (AI) based Decision Support Tools (DST) can be used to support operators in the execution of Air Traffic Flow and Capacity Management (ATFCM) and Air Traffic Control (ATC), Conflict Detection and Resolution (CD&R) tasks in a manner that can be understood by a human operator.

In support of this objective, a set of validation experiments will be performed that include 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 will be accompanied by a dedicated set of transparency tools, which provide interactive Visual Analytics (VA) and explanatory information, designed to help the human operator to understand the decisions being proposed by that automation.

The increasing 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.

In this scenario, a fundamental change in the automation approach from classical human-machine interfaces (HMI) to potentially richer solutions supported through AI and Machine Learning (ML) techniques is proposed. However, a significant challenge related to AI/ML solutions is the fact that these types of tools tend to be based on complex mathematical and highly recursive, deep searching, pattern matching algorithms to support the 'learning' process. As a result, this can render them difficult to comprehend by human users.

Using '*eXplainable* AI' (XAI) techniques, supported by enhanced *Visual Analytics*, it is hoped that reasons why certain solutions are being proposed by the DST will be able to be presented in an understandable way to the human operator and that the associated explanations can help build trust in the new technology as the level of automation increases. We recall that '*Trust*' in these new AI-based systems is paramount if the decisions being made are going to be widely accepted, and a potential lack of explainability would be detrimental to their future deployment or certification.

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

2 Introduction

2.1 Purpose of the document

The objective of this document is to provide details of the proposed Validation Plan and accompanying experiments for the TAPAS project.

It describes the proposed validation approach, available tools and systems that will be used to support the validation experiments, the required data and its origin, and the validation scenarios and exercises that will be performed to evaluate transparency solutions at varying levels of automation.

This version of the document provides details of validation activities for both the ATFCM use case and the Conflict Detection and Resolution use case planned to be executed in early 2022.

2.2 Intended Readership

This document is intended to be used by:

- SJU programme manager;
- TAPAS project members, in particular WP5, dealing with the execution of the validation exercises and the validation report.
- SESAR2020 and the international research community addressing automation in Air Traffic Management, Artificial Intelligence, Machine Learning and transparency/explainability principles.

2.3 Document Structure

The document is structured as follows:

- **Section 1 – Executive Summary**

  Provides a short summary of the document.

- **Section 2 (*this section*) – Introduction**

  Describes the purpose of the document, the intended readership, the background, and provides explanations of the abbreviations and acronyms used throughout the document.

- **Section 3 – Validation Context and Overview**

  Defines the context of the validation and provides a summary of the ATM domains, functionality and tasks that are being addressed by the analysis and the various automation solutions that have been implemented for validation purposes.

High level validation objectives are listed along with research questions and an initial planning for the proposed validation exercises is proposed.

A list of stakeholders with an overview of their needs and involvement is also provided.

- **Section 4 – ATFCM Validation Activities**

  Details assumptions and provides descriptions of the various scenarios that will be used to support the ATFCM validation activity.

- **Section 5 – ATC-CD&R Validation Activities**

  Details assumptions and provides descriptions of the various scenarios that will be used to support the ATC CD&R validation activity.

- **Section 5 – References**

  Provides a list of references.

2.4 Acronyms

Term	Definition
AI	Artificial Intelligence
ACC	Area Control Centre
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
DDR2	Demand Data Repository
DST	Decision Support Tool
FDPS	Flight Data Processing System
HITL	Human In The Loop
HMI	Human Machine Interface
INNOVE	INnovative Network Operations Validation Environment

Term	Definition
KPI	Key Performance Indicator
ML	Machine Learning
MTCD	Medium Term Conflict Detection
NM	Network Manager
OCVM	Operational Concept Validation Methodology
SACTA	Sistema Automatizado de Control de Tránsito / Automated System of Air Traffic Control
SESAR	Single European Sky ATM Research
STCA	Short Term Conflict Alert
SJU	SESAR Joint Undertaking
TAPAS	Towards an Automated and Explainable ATM System
TBO	Trajectory Based Operations
TRL	Technology Readiness Level
VA	Visual Analytics
XAI	Explainable AI

3 Validation Context and Overview

The motivation for the TAPAS project lies in the increasing desire to include AI and ML technology in the management and control of air traffic operations to help increase both the capacity of the ATM network as well as the ability of the Network Manager (NM) and Air Navigation Service Providers (ANSP) to offer a robust and reliable set of service to Airspace Users (AU). However, while AI/ML based solutions seem to offer technological solutions which can go beyond the more traditional deterministic solutions, understanding why AI and in particular ML using deep-learning techniques has proposed a specific solution can be difficult. Moreover, to help certify digital solutions which rely on these techniques presents a very real challenge as traditional development/test methods are difficult to achieve with solutions of this nature.

The TAPAS research aims to investigate how the use of XAI techniques combined with supporting visual analytics may help to deliver better transparency about how decisions have been reached by the AI/ML components. It is expected that these explanations will allow ATFCM and ATC experts to better understand why specific decisions have been made and that, over a period of time, sufficient trust can be achieved to allow them to be certified as reliable solutions that can be deployed to support ATFCM and ATC operators in their daily activity.

It should be noted, however, that as TAPAS is still an exploratory research activity, no attempt is made to try to identify 'how' AI/ML based solutions can be verified and certified. TAPAS will only focus on identifying methods by which the process can be explained to human operators to help them understand why (and possibly how) the decision has been made and why the proposed actions are appropriate.

The project proposes to study the introduction of XAI-based DST in two domains:

- Solution 1 will provide support to the Local Traffic Manager (LTM)/Flow Management Position (FMP) in performing collaborative network management activities in the Pre-Tactical phase [1].
- Solution 2 will focus on the tactical management of aircraft separation by Air Traffic Controllers (ATCo) during the execution phase [2].

Validation experiments will be performed individually for each of the two domains, using simulation platforms that have previously supported studies carried out during the SESAR 2020 programme. These are described in more detail in sections 4 and 5 later in this document.

Specific scenarios will be designed for each validation activity to evaluate if the prototype XAI and VA-components working at different levels of automation can provide sufficient levels of transparency for the human operator to understand and trust solutions. Automation will range from the provision of recommended actions identified by the tool so that the human operator can decide whether to apply that advice, to the automatic execution of those actions without involving the human in the process.

Analysis of potential use cases for the application of XAI solutions in each ATM domain has been performed as part of the WP2 activity in the TAPAS project. These are described in the D2.1 TAPAS Use Case Description document [3], in which a set of Operational Use-Cases have been identified.

For each selected use case, and at each of the selected levels of automation, the XAI analyse solutions and provide explanatory information. This will be further supported by carefully designed Visual Analytics to ensure transparency and foster a clear understanding of why those decisions have been made.

The study proposes to measure the level of transparency needed to help the human operator to understand the XAI at different automation levels, and to evaluate:

a) If the information provided allows the human to understand what has been proposed and why,

b) If the level of transparency provided is sufficient to maintain human understanding, even when the level of automation increases,

c) If there are areas where the transparency needs to be improved, and

d) If the human operators will accept that the proposals are based on good judgment and are appropriate for the situation being addressed, thereby promoting 'trust' in the technology.

Metrics that can be used to evaluate these issues are not easy to obtain. For this reason, it is anticipated that heuristic or qualitative indicators will need to be used. These will include (but are not necessarily limited to) the use of directed questionnaires, debrief analysis and 'over the shoulder' observation during the execution of exercises.

Although it is not the principle aim of the research to analyse the performance of the XAI tools in solving the ATM problems, some performance-related KPI will also be included in the experiments where possible, to provide additional insight into their effectiveness.

Given the innovative nature of XAI solutions, and the associated challenges in providing transparent information using VA to help the human to understand the complex recursive search methods used in deep learning ML solutions, the **main research objectives and challenges of TAPAS** are as follows:

Objective 1: Identify the principles and criteria for transparency and explainability that are required in support of AI/ML based automation in ATM domain.

Objective 2: Select and develop suitable and explainable AI/ML methods for ATM operational use cases that fit the needs of transparency as expressed in the explainability criteria developed for each level of automation level and according to operational stakeholder needs.

To support the main research objectives, **additional objectives and challenges** can also be considered as part of the TAPAS validation activity:

Objective 3: Assess how XAI and VA methods can help enhance operator understanding and trust in the solutions being proposed.

Objective 4: Evaluate the effectiveness of transparency solutions in support the deployment of AI/ML supported automation while maintaining operator situational awareness.

Objective 5: Demonstrate how transparency can promote social acceptance and eventual regulatory approval of AI/ML based digital solutions in the ATM domain.

Objective 6: Determine and deliver updated principles of transparency required to enable the deployment of AI/ML based automation for ATM.

3.1 TAPAS Research Questions

Specific research questions relating to the interaction between AI-based automation and human operators at different levels of automation (see section 3.2.1 below) will be considered as part of the TAPAS research. These include:

- For *all solutions* involving components that are based on ML:
  - How do the AI component developers ensure that the methods and data used to train the ML models are based on appropriate data and focus on relevant features?
  - How do the AI developers convince the operational users that the approach is valid?
- For *medium* levels of automation (Level 2):
  - How much additional information is required to ensure that the human operator is able to make informed judgements about which solutions can be applied to solve automatically detected ATFCM/ATC issues?
  - Is it necessary to provide additional information to the human operators that can help to explain the underlying algorithms that are used in the ML-based solutions – if so, how can that be best achieved?
  - Is the level of information sufficient to choose between different potential solutions?
  - If the information is not sufficient, how can the systems improve transparency and how much additional information is required to help the user to improve the level of understanding in the available timeframe?
- For *higher* levels of automation when the human is no longer involved in the decision-making process but continues to have a monitoring role (Level 3):
  - Is the human able to maintain a sufficient level of situational awareness to comprehend and explain solutions being made by the AI support tools?
  - How much additional information is required to ensure that the human operator is able to confirm that the solutions applied are appropriate in solving automatically detected ATFCM/ATC issues?
  - In the event that the support tool is no longer available (e.g., system failure, system degradation), can the human operators recover the situation, take over the process and complete it in a timely and reliable manner?
  - If the automation is not able to produce a solution for all the identified problems, can the human operator successfully solve the remaining issues based on the information provided?

  - Given the maturity of the proposed solutions, do human operators believe that sufficient levels of trust can be achieved (in the future) to facilitate operational and social acceptance and widespread deployment in the aviation domain? What would be the potential impact in the competences and training scheme required to maintain the human operator skills in this new context?

3.2 TAPAS Solutions and Validation Objectives

Based on the context, objectives, challenges, and research questions presented in the previous section, the validation approach will be based on two distinct validation phases, one focusing on ATFCM and the other on ATC CD&R.

Each phase will:

- Reproduce a realistic environment in which the human operators can perform their typical daily activities in the relevant domain using a Human-in-the-Loop (HITL) simulation platform and a suitable operational working position.
- Introduce prototype XAI components to provide automated DST support at different levels of automation in the simulated scenarios.
- Supplement the environment with additional VA support tools to address transparency requirements, provided via a dedicated interactive display.
- Design experimental scenarios that emulate varying levels of automation in which the prototype XAI/VA tools can be deployed and tested.
- Perform Human in the Loop (HITL) experiments to determine whether the proposed level of transparency and explanatory information is sufficient to ensure human understanding and situational awareness.

Additional details for each of the proposed solutions that are being assessed by TAPAS are provided later in this document.

3.2.1 Levels of Automation

The TAPAS D2.2 Consolidated Requirements and Functional Roadmap proposes that the project will consider different levels of automation in line with the definitions found in the European ATM Master Plan [4] when designing its validation scenarios.

The definition mirrors the Levels of Automation Taxonomy (LOAT) model that is used by the Society of Automotive Engineers in its self-driving vehicle automation research and is expressed using *five levels of automation* described below:

- **Level 0 – Low Automation**

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

- **Level 1 – Decision support**

Automation supports the human operator the acquisition, exchange, and analysis of information and provides recommendation of actions that can be selected for some tasks/functions.

- **Level 2 – Task Execution Support**

Automation supports the human operator in the acquisition, exchange, and analysis of information then selects and prepares appropriate actions for some tasks/functions.

However, the implementation of those actions remains under the management of the Human Operator.

Adaptable/adaptive automation concepts can also support optimal socio-technical system performance.

- **Level 3 – Conditional Automation**

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

Appropriate actions are selected and can be automatically implemented by the system for most tasks/functions.

Automation can initiate actions for some tasks, but not necessarily all of them.

The human operator remains responsible for the implementation of the remaining actions.

Adaptable/adaptive automation concepts can also support optimal socio-technical system performance.

- **Level 4 – High Automation**

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

Action selection and implementation is performed by the automation for all tasks/functions.

However, the human operator is still able to intervene in the process and override the automated action if needed.

Adaptable/adaptive automation concepts can also support optimal socio-technical system performance.

- **Level 5 – Full Automation**

Automation performs all tasks/functions in all conditions.

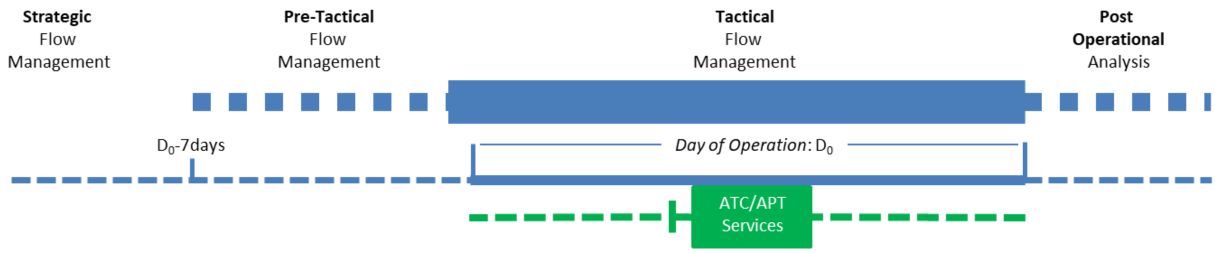
There is no human operator in the process.

3.2.2 ATFCM Solutions

In Europe, the EUROCONTROL Network Manager unit (NM) has been mandated with the role of planning and managing all traffic operations performed in the ATM and Airport network to help provide an efficient level of service to Airspace Users under varying levels of demand.

The core function of that role is the provision and support of Air Traffic Flow and Capacity Management services.

ATFCM is a collaborative process that involves many actors, including NM, regional flow managers, airspace management units, airport planners, airspace users (airlines) and the military, to name a few. Its objective is to manage the balance of demand and capacity through the optimisation of the available resources and provision of coordinated responses to ensure the quality of service and performance of the ATM/Airport network in a safe and efficient manner.



ATFCM provision in the ECAC area is performed in four main phases [5]:

Strategic Flow Management: is a long-term planning process that takes place seven days or more prior to the Day of Operations (D).

It includes research, planning and coordination activities that are performed through a Collaborative Decision Making (CDM) process and comprises a continuous data collection and review of procedures with the identification of measures that are directed towards early identification of major demand/capacity issues such as: principal axis management, air shows, major sporting events, military exercises, etc.).

The output of this phase is the *Network Operations Plan* (NOP).

Pre-Tactical Flow Management: is applied during the week leading up to the day of operations (i.e., D-7 to D) and consists of planning and coordination activities. It studies the predicted demand for the day of the operation and compares it with the predicted capacity for that day.

The main objective of the pre-tactical phase is to optimise efficiency and balance the predicted demand against the available capacity (from the NOP) through an effective organisation of resources. This is achieved through a variety of methods, including sector configuration management, use of ATFCM scenarios, etc. and the implementation of a wide range of appropriate ATFCM measures.

The work methodology is based on a CDM process between the stakeholders (e.g., NM, regional FMPs, Airports, Airspace Users, Military) through the identification of regional demand–capacity imbalances within the network (optionally declared as ‘Hotspots’) and the establishment of cooperative actions that can be applied to help resolve the issues.

The output is the *ATFCM Daily Plan* (ADP) which is published by NM.

Tactical Flow Management: takes place on the day of operations (D) and typically involves real time identification of events that affect the ADP and require modifications to support Demand-Capacity Balancing.

The main objective of this operational phase it to ensure, in collaboration with regional stakeholders and airlines, that the measures that were applied during the strategic and pre-tactical phases are still suitable to solve demand / capacity imbalances and if needed, to adjust the original plans in response to unanticipated disturbances such as staffing problems, meteorological issues, crises and special events, unexpected limitations related to ground and/or air infrastructure issues, etc.

The tactical phase will also take advantage of any opportunities that may arise to enhance network performance so the provision of up to data and accurate information is of vital importance in this phase.

Post Operational Analysis is the final phase in the ATFCM process and takes place following the tactical phase of operations. In short it is an analytical process designed to assess how the measures applied performed with respect to their performance targets.

The output of this phase is the development of best practices and/or lessons learnt for improving upon those operational processes and activities.

3.2.3 TAPAS ATFCM XAI/VA Solution Scope

The TAPAS research and the associate validation scenarios will focus on ATFCM solutions in the **Pre-Tactical Flow Management** phase and specifically on **Demand-Capacity Balancing activities** for a selected region – mainland Spain.

The scope of the XAI solutions will be limited to allow the focus to be placed on the explainability and transparency components of the DST, rather than developing solutions to address the entire range of ATFCM measures, Dynamic Airspace Configuration or Flexible Use of Airspace/Dynamic Mobile Area concepts. For this reason, solutions that address the uses cases identified in TAPAS D2.1 will be used to detect, declare and resolve imbalances in the Pre-Tactical phase.

In particular, the focus will be on the D-1 planning activity, which has much more reliable flight plan predictions available for use in the DCB process. This will allow the XAI automation to consider both imbalances due to capacity issues as well to look for opportunities to improve the level of performance to better suit the anticipated demand.

Scenarios will focus on the Local Traffic Manager (LTM) or Flow Manager Position (FMP) with support from the ANSP ACC Supervisors and NM, where needed.

Demand-Capacity issues will be identified using the existing approach that is applied by NM in their existing B2B services, namely the use of Hourly Entry Counts, Occupancy Counts, Hourly Capacity Thresholds, Peak/Sustained Occupancy Thresholds and Occupancy Traffic Monitoring Values (OTMV). However due to the limited scope of the XAI tools, only the Hourly Entry Counts (Demand) will be used in the experiments.

Solutions considered by the XAI are based on those that are currently used by NM and its regional partners and do not attempt to consider some of the more conceptual or research oriented ATFCM solutions. Currently these include the use of Regulations to traffic (delays) and/or Reroute proposals:

Regulations in the NM system are created in response to the identification of Airspace Sectors or Traffic Volumes that are expected to be overloaded for a given time-period. Such situations can be further highlighted by NM through the declaration of one or more Hotspots that can be used to share the problem information with other collaborating partners.

When a flight is included in a Regulation, it may be subject to a delay that is imposed at its departure airport. When operating in the entire ECAC network, flights may interact with several Hotspot areas, so a mechanism is included in the NM system which considers all of the Regulations that each flight is included in and which identifies the Most Penalising Regulation (MPR). These calculations are performed using the Computer Aided Slot Allocation (CASA) tool using the True Revision Process (TRP). TRP is executed each time that a new Regulation is added in the network, or when the characteristics of Regulations change (e.g., if the Hotspot/Regulation period increases or a new one is identified).

Reroute Measures allow NM and local stakeholders to apply temporary modifications to proposed flight plans to reduce the demand in a specific region by diverting traffic into other less busy areas. In the latest version of the NM platform, reroute measures are usually based on ATFCM scenarios that have been developed by NM and local partners to help manage problems that occur regularly in a specific region. ATFCM scenarios provide template solutions which can then be 'fine-tuned' by NM and local FMP to tailor them to the specific issues of the problem that has been identified. Currently, reroutes can be achieved using either level-based modifications (e.g., **Flight Level Capping** to keep traffic below a problem area, before allowing it to climb again once it is clear of the problem) or lateral modifications (i.e., provision of a temporary lateral reroute to **avoid** the problem or **go via** neighbouring airspace that is less busy).

Mitigation actions considered by the automated XAI solutions will be limited to the use of either **ATFCM Regulations** or **ATFCM Reroutes using Flight Level Capping** (FLC). The XAI component developed in TAPAS may also provide solutions that are based on a combination of the two. More information of the ATFCM use cases can be found in Section 4 of the TAPAS Operational Use Case Description [3].

The XAI ATFCM component has been trained using one AIRAC cycle of historical traffic data and ATFCM data (AIRAC cycle 1908), provided by CRIDA/ENAIRE, to help the system learn how ATFCM solutions are typically used in the Spanish region.

To evaluate how the tools will respond to other situations, a series of new 24-hour scenarios will be provided to allow the XAI component to identify areas where demand/capacity issues are encountered (Hotspots). Using these scenarios, the deep learning neural network will be executed to help identify suitable solutions for all the issues found for the entire 24-hour period [6].

Although training data has focused on problems and solutions that were identified in the Madrid ACC, it is also hoped that the resulting ML algorithms will be able to support the identification and solution issues in the other Spanish ACC. However, this potential constraint to the approach should be kept in mind when analysing the results for these other regions.

Additionally, to ensure that any specific features that may be present in the experimental data that is planned to be used for the study the XAI model will be trained further using some of the data from the target AIRAC cycle prior to executing the actual validation scenarios.

The XAI tool will be integrated with a working position that will provide both an FMP client interface and a Visual Analytics display.

- The FMP working position will provide similar features to a typical operational interface.
- The VA display will provide visualisation and accompanying explanations that are provided to help a human operator understand how a given decision was reached and why the particular solution was selected/proposed/implemented.

The tools will also be integrated with the INNOVE Network Management simulation and gaming platform which will be used to simulate the NM B2B services and functional processes during the execution of the pre-tactical planning process.

Experiments will be performed for each of the three target levels of automation with the allocation of the human/automation roles as illustrated in the table below:

ATFCM Functions / Tasks	Automation Level 1	Automation Level 2	Automation Level 3
Traffic Demand Monitoring	Machine	Machine	Machine
Identification of imbalances	Machine	Machine	Machine
Analysis of the imbalances detected	Human	Machine	Machine
Identification of hotspots / optispots	Human	Machine	Machine
Declaration of hotspots / optispots	Human	Human	Machine
Preparation of DCB measures to solve the hotspot	Human	Machine	Machine
Decision on the DCB measure and flights impacted	Human	Human	Machine
Implementation of DCB measures	Human	Human	Machine
Hotspot resolution monitoring	Human	Machine	Machine

Table 1: ATFCM Automation Allocation

Note: as three separate scenarios are planned, each at a different level of automation, it will imply that three individual analysis datasets from different dates will be necessary to support the validation.

3.2.4 CD&R Solutions

The second set of XAI/VA solutions concern the Conflict Detection and Resolution process that is carried out by air traffic controllers via the Controller Working Position (CWP) as part of the separation assurance process at the tactical phase (see the TAPAS Use Cases Description for a more detailed description of the CD&R use case) [3].

Airport Operators and Air Navigation Service Providers across Europe are responsible for the supply of Air Traffic services (ATS) for all flight operations in the region in line with the plans established during the ATFCM process.

This includes providing the airspace users with:

- Air Traffic Control Services
- Air Traffic Advisory Services
- Flight Information Services
- Alerting Services
- Civil/Military Coordination Services
- Airport Ground Movement Management Services
- Support for Airport Collaborative Decision Making (A-CDM) processes

ANSP also provide technical support for various services required to facilitate the safe transition of aircraft through the managed airport and airspace system including Communication Navigation and Surveillance Services (CNS), Meteorological Services (MET) and Aeronautical Information Services (AIS).

The main objectives of ATS can be generally considered to be as follows (but are not necessarily limited to this set):

- Prevention of collisions between aircraft in flight
- Prevention of collisions between aircraft (or aircraft and other vehicles/persons/animals) on the airport manoeuvring area
- Prevention of collision between aircraft and terrain
- Prevention of collision between aircraft and obstacles/obstructions (in or around the airport environment)
- Expedition and maintenance of orderly flows of traffic
- Provision of information and advice in relation to the safe and efficient conduct of flight operations
- Support to search and rescue operation as required

3.2.5 TAPAS CD&R XAI/VA Solutions Scope

The TAPAS research relating to ATC CD&R, and the associate validation scenarios, will focus on ATS Services that support the **Prevention of Collisions between Aircraft in Flight**. This Separation Management activity is a key element of the daily ATC task and is broken down into two main activities: **Conflict Detection** and **Conflict Resolution (CD&R).**

CD&R scenarios will be based on concepts and principles that are commonly used for en-route airspace scenarios in the Spanish airspace.

Additional scenarios based on Flight Centric Airspace concepts [7] may also be considered if time permits to test if the XAI prototype works fine within this context, but the system will be trained with data coming from current operations and, therefore, the main validation scenarios will be tailored to the current operations.

Experiments will be performed for each of the three target levels of automation in support of the Conflict Detection and Resolution process, with the allocation of the human/automation roles as illustrated in the table below:

(Executive Controller) CD&R Functions / Tasks	Automation Level 1	Automation Level 2	Automation Level 3
Assessment of the planned and preferred trajectories	Machine	Machine	Machine
Identification of potential conflicts	Machine	Machine	Machine
Identification of resolution strategies & possible clearances	Human	Machine	Machine
Implementation of selected clearances	Human	Machine	Machine
Conformance monitoring	Human	Human	Machine
(non) Conformance monitoring & resolution	Human	Machine	Machine

Table 2: CD&R Automation Allocation

Note that many ATC Flight Data Processing Systems (FDPS) and Controller Working Positions (CWP) already provide a significant level of automated support in the separation management / conflict detection domain so it is assumed that this process (i.e., conflict detection) will be automated at all levels of automation targeted in the TAPAS validation scenarios.

3.2.6 Transparency

As stated previously, the ultimate objective of the TAPAS research is to capture clear and concise principles and recommendations to achieve levels of transparency for AI/ML based DST that can allow the human operator to understand how and why solutions have been selected for any given situation.

It is expected that achieving this goal would in turn help to build operator trust in the proposed technology, as well as to support the verification of such systems in a deployment scenario.

Additionally, the research is intended to pave a way forward towards further uptake of AI/ML based techniques in support of enhanced automation and an eventual increase in the capacity and efficiency of the ATM system as a whole.

AI-based solutions are not new in the IT domain and have existed since the 1970's or earlier. However, with the recent re-emergence of interest in AI and ML based technology and advances in computing power seen in the last 5-10 years, the application of AI is becoming commonplace for solutions where automated support is concerned. The ATM domain is no exception to this.

However, since AI techniques often rely on high powered statistical methods that are usually deeply recursive, the understanding and verification of these algorithms can be a challenge if such solutions are to be widely adopted, particularly in safety-critical applications.

The concept of trust in AI solutions represents a significant challenge. This is magnified when safety is a concern.

In response to these challenges, and the need for humans to understand how the AI came to a given solution, organisations around the world have set up expert groups to help to elaborate a strategy on AI and to consider the societal and trust elements of the technology.

In particular, the EUROCAE and SAE, WG-114 and G-34 working groups have been developing a set of guidelines for the development, certification, and deployment of AI-based tools, particularly in safety critical applications. These guidelines recognise that explainability is a major axis for the certification effort for AI automation.

The TAPAS project will therefore explore the concepts of transparency and explainability for AI/ML systems and looks to provide trustworthy automation that can be clearly explained in the two selected ATM domains.

The XAI solutions that are being developed by the project partners will be supported by a set of VA visual support tools to help promote trust in the automation and gain human acceptance. An additional challenge, to provide explanations and information that are relevant to the specific domain, will also be addressed in the TAPAS solutions.

Finally, the time horizon in which the decisions are being made is also a major contributor to the level of explanation or transparency that will be required, as well as the safety criticality.

For example, in the proposed ATFCM solutions, decisions that may help improve the use of available capacity are made the day prior to actual operation (D-1). However, in the CD&R solutions, decisions must be made a very short time ahead of the identified problem and solutions are highly safety critical. Hence the need for transparency and the time available to provide suitable explanations are very different in each of the selected domains:

- DST support to the ATFCM process can be supported using on-line transparency support. This approach allows the user to interrogate the explanations and potentially drill down to obtain more detail, even for the most complex situations, since time is usually not a constraint.

- However, in support of CD&R, the very short lead time in which to make and apply safety-critical decisions, and the high level of pressure to ensure that solutions are appropriate, means that there is little or no time to provide detailed explanations to the operator. However, it remains critical that the user can understand the decisions and why a given solution has been chosen, so this must be achieved through off-line transparency methods [8].

This is summarized in the diagram below:

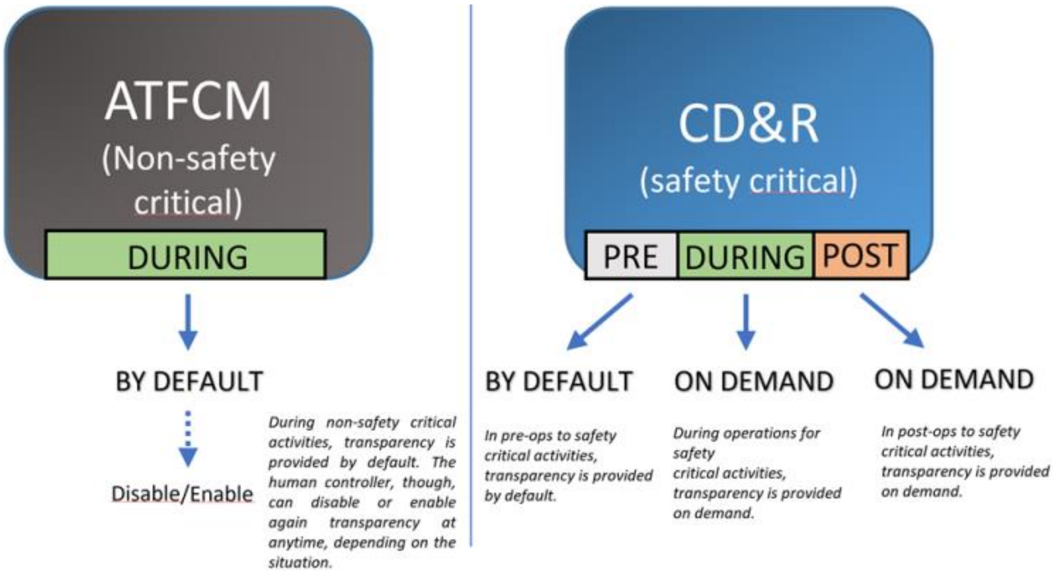


Figure 1: ATFCM / CD&R Transparency Approach

Transparency support planned for the ATFCM automation validation process is focused on (*but not necessarily limited to*) the following high-level features:

- Hotspot identification and imbalance analysis support including
  - Decision / rules that can be applied for the identification of a hotspot
  - Rules that contributed to each hotspot that was identified
- Sector visualizer, including
  - Providing operators with easy-to-use visual evidence of sector overloads
  - Clustering similar trajectories to capture large/small flows
- Available / selected / applied DCB measures, including
  - Most effective solution(s) chosen by the XAI DST
  - Parameters / features that contributed to the decision process
  - Regulation / delays and re-routings applied to traffic / flows
  - Preliminary views of the impact/performance of the solution(s)
  - Flights concerned
  - Areas that have been 'off' or 'on' loaded as a result of the measure(s)
  - Verbose textual 'explanations' to support the reason that the solution has been proposed
- Explanations to help understand which flights have been selected/proposed for measures

- Solution performance indicators, for example
  - No of impacted flights
  - Mean, median delays to traffic
- Alternative solutions (if available)
- Support for *What-If* impact analysis of other opportunities
- Impact analysis

More detail on the approach and features being provided in support of ATFCM transparency is available in the TAPAS Integrated Prototype description [9].

Transparency support planned for the CD&R automation validation process is focused on (*but not necessarily limited to*) the following high-level features:

- Planned and preferred trajectory comparison
  - Providing the operator with clear information on the impact on flight trajectories
  - Highlighting differences to flight performance (lateral, vertical, speed) between planned/preferred and actual profile(s)
  - Visualisation of flight impacts and location
  - Textual justification and explanation of the differences
- Conflict Identification and characteristics
- Identification of available resolution strategies for each case
- Short and verbose text-based reasons and justification for the choice of solution
- Analysis of impact to flight due to proposed/selected/executed action
- Conformance monitoring

3.3 Stakeholder identification, needs and involvement

The following table identifies potential stakeholders and their domain of interest in the TAPAS research:

Area	Organisations	Interest	Key Information	Importance	Measure of Success
Sponsor	EC, SJU	Proposal compliance Promotion and dissemination of results to interested parties	Project on-time, in scope and within budget	High	Project milestones and deliverables are completed in line with the schedule and budget envelope. Project results are shared with interested parties through publications, social media and at conferences
Academia, Research	Universities EUROCONTROL, CRIDA	Academic achievement	Research results and findings, method used to achieve reliable levels of explainability	High	Technical research papers describing the theoretical approach used in the XAI and VA solutions are published and distributed among the academic community. Results and proposals for future tasks are taken up by researchers in future projects.
ATFCM	Network Manager (NM),	Efficient planning of network	Level of Trust in	High	Operational solutions and

Area	Organisations	Interest	Key Information	Importance	Measure of Success
	Regional FMP, Airports	resources, flexibility of automated solutions, efficiency of solutions, transparency	automation, reliability of solutions, acceptance by operators		in particular the method used to promote transparency are adopted by the wider ATFCM community. Operational users show high levels of understanding of the support tools.
Air Navigation Service Providers	National ANSP, CANSO	Efficient use of resources, enhanced automation, proposed CF resolutions, transparency	Level of Trust in automation, reliability of solutions, acceptance by operators	High	XAI solutions supported by VA explanations allow ANSP to improve their capacity and reduce workload on the operational teams
Airspace Users	Airlines, IATA	Efficient use of resources, enhanced capacity, impacts and delay	Impact to airline operations, efficiency, delay, costs	High	Users suffer lower impacts to proposed operations and are able to execute on-time flights that are closely aligned with what was originally planned.

Area	Organisations	Interest	Key Information	Importance	Measure of Success
Industry	Industry companies	Automation 'take-up' and acceptability	Acceptable levels of automation, efficiency, reliability of solutions, level of trust in automation, transparency, functional architecture	High	Industrial solutions used in support of the TAPAS research are able to incorporate more mature versions of the XAI/VA prototype tools for eventual deployment in the field
Public		Efficiency, cost, safety	Punctuality, on-time performance, cost, accident risk	Medium	General acceptability that AI-based solutions are able to produce safe and effective solutions in the aviation domain

Table 3. Identified stakeholders, needs and involvement of TAPAS project.

3.4 Validation Approach

This section describes the approach that will be applied to the validation in both the ATFCM and the ATC-CD&R domains. It also provides details of the validation platform and scenarios for each analysis case.

Metrics and Key Performance Indicators that can be used to help to determine the level that the objectives of the TAPAS research have been satisfied (or not) by the XAI and VA solutions created in other TAPAS WP are also identified.

The validation approach applies methods and best practices described in the SESAR Requirements and V&V Guidelines [10].

Based on the TAPAS research objectives, the validation approach will be based on the following steps for each of the target ATM domains:

1. ***Reproduce a realistic (ATFCM/ATC-CD&R) environment*** to support the execution of validation scenarios at varying levels of automation

2. ***Integrate the (ATFCM/ATC-CD&R) XAI and VA components*** into the validation platform

3. ***Verify the (ATFCM/CD&R) validation platform*** with the integrated XAI/VA components using carefully prepared test scenarios

4. ***Train the (ATFCM/ATC-CD&R) XAI learning components*** using suitable archive data (provided by ENAIRE/CRIDA)

5. ***Select new (ATFCM/ATC-CD&R) data to create suitable analysis scenarios*** for each level of automation

6. ***Tune and test the (ATFCM/ATC-CD&R) validation scenarios*** for each level of automation

7. ***Brief operational users*** in the scope, objectives and their expected activities/role for each scenario and each level of automation

8. ***Execute the validation scenarios*** using a series of HITL simulation exercises and gather appropriate outputs and metrics to support the required KPI

A description of the experimental scenarios that will be used for the validation is provided in section 4 (for the ATFCM experiments) and section 5 (for the CD&R experiments), later in this document.

3.5 High-level Validation Objectives

The main objective of the proposed validation is to assess how enhanced automation support tools based on new AI/ML technology might be deployed in the ATFCM and ATC-CD&R domains in a manner that allows operational users to achieve a good understanding of the solutions that are being proposed and why.

As mentioned previously, due to the complex recursive nature of deep-learning AI solutions, it can be very difficult for users to understand how the system is making certain decisions and what features were influential in arriving at the solution(s).

This issue is further compounded as the level of automation of the DST increases:

- At lower levels of automation, the human operator remains an active participant in the decision making and therefore is complicit in the process and able to maintain situational awareness.

- As automation levels increase and the human becomes less involved. As this happens, understanding is likely to decrease and risks reduction in, or loss of situational awareness. Over the longer term this has the potential of resulting in a reduction in skills and possibly even a loss of expertise.

Hence the aim of TAPAS is to extend the AI techniques being used to create the automation tools through the application of XAI techniques, and as automation levels are increased, to utilise VA based support tools and technology to help maintain the transparency of the tools, the decisions that have been made and the reason(s) behind them.

The tables below provide a summary of the main objectives and research questions that will be considered during the ATFCM and ATC-CD&R exercises:

ATFCM Validation Objective	Sub-Focus		Success Criteria		Associated Activity
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.	1.1.1	VA and explanatory support information is clear and understandable and the tools are able to provide the required information at the right time.	A dedicated VA/Transparency screen with VA support graphics and explanations will be developed and co-located with the FMP working position. XAI prototype tools shall be designed to produce suitable data to feed VA views.
	1.2	Identify when support information is required, what level of detail is needed and how should it be provided in a timely manner.	1.2.1	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.	Human operators working the FMP position will use the data displayed via VA support media to help in the comprehension of what the AI tools are proposing and why.
	1.3	Evaluate areas where the levels of transparency may need to be improved.	1.3.1	Information that is unavailable but could help during the use of the proposed XAI has been identified and catalogued for future analysis.	Paper based/mock-up review of transparency views are carried out in cooperation with domain experts to help identify other useful data/views.
	1.4	Propose suitable methods by which the level of understanding and trust in the AI automation can be measured.	1.4.1	Questionnaires, 'over-the-shoulder' observation and debriefing analysis metrics have been identified to support the necessary measures.	The TAPAS research team will design a set of suitable questionnaires, observation and debriefing techniques to help analyse the required measures
OBJ2: Develop prototype XAI/VA methods for ATM use cases to address transparency at	2.1	Produce customised VA views to support transparency and explanatory information to the human operator at	2.1.1	VA display tools are able to consume data provided by the XAI component to support interactive drill down	XAI components are designed by the TAPAS research team that can produce data in support of

ATFCM Validation Objective	Sub-Focus		Success Criteria		Associated Activity
various levels of automation		different levels of automation.		views for the human operator	proposed visual analytics. Visual data presentations have been designed by the TAPAS research team to support the presentation of scenario information to help support understanding and explanatory information.
	2.2	Assess how the VA methods can help enhance operator understanding and trust in AI-based automation.	2.2.1	Elements provided in the VA provide clear visual evidence related to the actions being performed by the XAI tools	VA and data analysis/presentation experts have produced new visual support views to help support the human operator when trying to follow the reasoning of the XAI processes and scenarios
	2.3	Evaluate the effectiveness of the transparency solutions being deployed.	2.3.1	Human operators are able to use the visualisation to interrogate the on-going scenario and solutions being considered	Interactive visual components with the ability to drill down to discover more detail have been developed by the TAPAS team
	2.4	Determine the different needs for transparency at different automation levels	2.4.1	Human operators classify the information being provided and confirm that it is sufficient to explain the decisions being made	The validation team will perform 'over the shoulder' observation to assess
	2.5	Evaluate the level of understanding and situational awareness of the human as the automation proposes / implements solutions	2.5.1	Human operators are able to describe what the automation is doing and why solutions have been proposed.	Discussion and directed questions with the operator during the exercises will help determine the level of understanding
	2.6	Verify that the human can successfully take over and recover control of the	2.6.1	The human was able to either take over and complete the current	Random 'emulated failure' of automation is

ATFCM Validation Objective	Sub-Focus		Success Criteria		Associated Activity
		situation if the automation fails for any reason		task when automation failed,	considered as an optional scenario
	2.7	Ensure that the human is able to identify and resolve any remaining issues at the end of the XAI process, if present.	2.7.1	The human operator was able identify and to complete any remaining issues that were not successfully solved at the end of the process	If DCB issues remain at the end of the process the human is able to identify and resolve them
	2.8	Demonstrate how transparency can promote operational and social acceptance of 'black-box' AI solutions	2.8.1	The operator confirms that the solutions provided by the XAI were fit for purpose	At the end of any exercise a debrief session will be held that includes an evaluation of the solutions by the operational experts in the domain
	2.9	Assess shortfalls and areas where transparency can be improved in future solutions	2.9.1	Operational experts identify areas where information was insufficient to support understanding	At the end of any exercise a debrief session will be held to allow operational experts to identify any shortfall in the process.
	2.10	Identify opportunities for additional training	2.10.1	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	During the debrief and post experimental analysis, opportunities to provide additional training will be investigated

Table 4. TAPAS ATFCM Validation Objectives

CD&R Validation Objective	Sub-Focus		Success Criteria		Associated Activity
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 conflicts identified by the system at various levels of automation.	1.1.1	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	A dedicated VA/Transparency screen with VA support graphics and explanations will be developed and co-located with the Executive Controller Working Position (CWP).

CD&R Validation Objective		Sub-Focus		Success Criteria	Associated Activity
				managed and context of the proposed solution.	XAI prototype tools shall be designed to produce suitable data to feed VA views and data to be presented is concise and easy to assimilate by the ATCo.
	1.2	Identify when support information is required, what level of detail is needed and how should it be provided in a timely manner.	1.2.1	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.	Human operators working the sector position will use the data displayed via VA support media to help in the comprehension of what the AI tools are proposing and why. If required, the ATCo is able to choose to investigate further, using more detailed information and this information is made available and able to be understood by the ATCo to allow them to make an informed decision on the subsequent action with sufficient time remaining to implement that action or to propose an alternative.
	1.3	Evaluate areas where the levels of transparency may need to be improved.	1.3.1	Information that is unavailable but could help during the use of the proposed XAI has been identified and catalogued for future analysis.	When reviewing the data and VA tools that have been provided to the ATCo, any missing elements which would have helped improve the understanding and acceptance/rejection of the proposed action(s) by the ATCo will be identified and catalogued for future consideration.

CD&R Validation Objective	Sub-Focus		Success Criteria		Associated Activity
	1.4	Propose suitable methods by which the level of understanding and trust in the AI automation can be measured.	1.4.1	Questionnaires, 'over-the-shoulder' observation and debriefing analysis metrics have been identified to support the necessary measures.	The TAPAS research team will design a set of suitable questionnaires, observation, and debriefing techniques to help analyse the required measures. Solutions proposed by the XAI tools are able to successfully solve the identified issues in an acceptable timeframe or be rejected by the ATCo and an alternative solution can be actioned in a safe time window.
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.	2.1.1	VA display tools are able to consume data provided by the XAI component to support interactive drill down views for the human operator	XAI components are designed by the TAPAS research team that can produce data in support of proposed visual analytics. Visual data presentations have been designed by the TAPAS research team to support the presentation of scenario information to help support understanding and explanatory information.
	2.2	Assess how the VA methods can help enhance operator understanding and trust in AI-based automation.	2.2.1	Elements provided in the VA provide clear visual evidence related to the actions being performed by the XAI tools	VA and data analysis/presentation experts have produced new visual support views to help support the human operator when trying to follow the reasoning of the XAI processes and scenarios

CD&R Validation Objective	Sub-Focus		Success Criteria		Associated Activity
	2.3	Evaluate the effectiveness of the transparency solutions being deployed.	2.3.1	Human operators are able to use the visualisation to interrogate the on-going scenario and solutions being considered	Interactive visual components with the ability to drill down to discover more detail have been developed by the TAPAS team
	2.4	Determine the different needs for transparency at different automation levels	2.4.1	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.	The validation team will perform 'over the shoulder' observation to assess the proposed success criteria. Additional metrics (e.g. Time to Conflict, different types/levels of explanations) can be used to determine if actions are implemented in an acceptable time prior to the start of the identified issue and/or which needs for transparency are required.
	2.5	Evaluate the level of understanding and situational awareness of the human as the automation proposes / implements solutions	2.5.1	Human operators are able to describe what the automation is doing and why solutions have been proposed.	Discussion and directed questions with the operator during the exercises will help determine the level of understanding. Post exercise debrief and questionnaires will be used to further support that analysis.
	2.6	Verify that the human can successfully take over and recover control of the situation if the automation fails for any reason	2.6.1	The human was able to either take over and complete the current task when automation failed,	Random 'emulated failure' of automation is considered as an optional scenario or users will be randomly requested to reject the 'proposed' solution in favour an alternative that they develop themselves

CD&R Validation Objective	Sub-Focus		Success Criteria		Associated Activity
	2.7	Ensure that the human is able to identify and resolve any remaining issues at the end of the XAI process, if present.	2.7.1	The human operator was able identify and to complete any remaining issues that were not successfully solved at the end of the process	If conflict situations are not able to be suitably resolved by the automation, the human is still able to identify alternative actions and has time to implement them with a suitable safety margin
	2.8	Demonstrate how transparency can promote operational and social acceptance of 'black-box' AI solutions	2.8.1	The operator confirms that the solutions provided by the XAI were fit for purpose	At the end of any exercise a debrief session will be held that includes an evaluation of the solutions by the operational experts in the domain
	2.9	Assess shortfalls and areas where transparency can be improved in future solutions	2.9.1	Operational experts identify areas where information was insufficient to support understanding	At the end of any exercise a debrief session will be held to allow operational experts to identify any shortfall in the process.
	2.10	Identify opportunities for additional training	2.10.1	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	During the debrief and post experimental analysis, opportunities to provide additional training will be investigated

Table 5. TAPAS CD&R Validation Objectives

3.6 Validation Planning

The different validation topics will be addressed in two distinct phases:

Phase 1 will focus on the ATFCM validation and will be performed using the **ISA INnovative Network Operations Validation Environment (INNOVE). INNOVE** is based on the ISA Collaborative Human In the Loop (CHILL) simulation platform and has been developed in cooperation with EUROCONTROL to provide a fully interoperable simulation and HITL collaborative gaming platform supporting the most recent NM 24.0 B2B services as well as a number of prototype services and features that have been specifically developed to support SESAR validation activities.

Phase 2 will address the ATC CD&R validation using the Real-Time Simulation (RTS) platform that is available at ENAIRE/CRIDA, which is based on the current system that is deployed in support of all ATC services for the Spanish airspace – SACTA (Sistema Automatizado de Control de Tránsito / Automated System of Air Traffic Control). SACTA facilitates delivery of all ATS (Air Traffic Services) for which ENAIRE is responsible and it integrates all Spanish en-route, approach, and terminal centres to ensures coordinated management based on consistent data to provide interruption-free operation between all Spanish Air Traffic Control units.

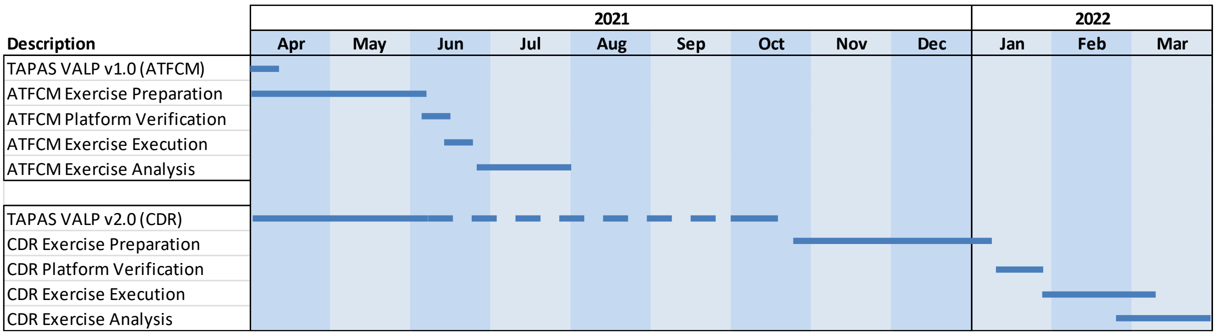
In this role, SACTA supports all the following ATC functions:

- **Processing of all flight plan information** through the central processing of flight plans (TCPV) and multiple instances of local processing of flight plans (TLPV).
- **Traffic planning** tools.
- **Radar data processing** to support the functions of aircraft monitoring and identification and for maintaining air traffic separation.
- **Track correlation –** providing the link between radar information and flight plans to allow the automatic and unambiguous identification of aircraft by controllers.
- **Presentation of weather information** to assist with navigation in adverse conditions.
- **Conformance monitoring** and the provision of alerts to controllers in case of aircraft deviations from the planned route or with respect to permissions received in real time.
- **Data communication** in the form of datalink exchanges between the aircraft and the controller, allowing direct message exchange with aircraft, and thereby avoiding time consuming oral communication.
- **Aeronautical information management** for air traffic control working positions.
- **Distributed monitoring, configuration, recording** and technical exploitation of the entire system, which can be used to share information with external components and to gather data in support of post operations analysis activities.

In support of the CD&R validation experiments, the SACTA based RTS will be used to perform a series of exercises with ATCo working one or more ATC working positions (sectors) for dedicated scenarios in which a variety of pre-determined and potentially unplanned conflicts situations may occur. Each exercise will be supported by an integrated XAI decision support component and suitable VA display tools with varying levels of automation available to the human operators.

Additional details of the validation platform infrastructure that will be deployed to support each of the experimental scenarios are provided in section 4.3 and 5.3 of this document.

The two validation phases are planned in accordance with the following schedule:


2021
2022
Description
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
TAPAS VALP v1.0 (ATFCM)
ATFCM Exercise Preparation
ATFCM Platform Verification
ATFCM Exercise Execution
ATFCM Exercise Analysis
TAPAS VALP v2.0 (CDR)
CDR Exercise Preparation
CDR Platform Verification
CDR Exercise Execution
CDR Exercise Analysis

4 ATFCM Validation Activities

This section describes the validation scenarios and experiments that will be performed in the ATFCM domain to help to assess the impact or success of the introduction of AI-based automation and decision support systems with varying levels of automation. The focus is on the ability for human operational experts to understand what is being proposed by the tools and why. As the levels of automation increase across different scenarios, analysis of the transparency of proposed solutions will be assessed, as well as the level of operator trust in the tools.

The main objective of the ATFCM validation is to assess the impact of the inclusion of the XAI automation tools on current ATFCM working methods and, in particular, how the human operator interacts with those tools.

From the transparency perspective, the objective is to evaluate how the various VA components and support tools can inform the human operators to a sufficient degree that they can understand what is being proposed, and why.

As part of these objectives, the validation will also try to measure the level of situational awareness that the human is able to maintain in any given situation.

Finally, we will try to assess whether situational awareness is diminishing as automation increases in the level of XAI support or not.

The analysis considers the following three Key Performance Areas:

- Human Performance
- Efficiency
- Safety

It is important to note, however, that due to the low TRL for the current research, which is estimated to be TRL 1, the AI/ML prototypes that are being developed to support the automation will be focused on *testing the approach from the perspective of supporting human understanding* and *are not specifically designed to enhance or improve existing solutions*. For this reason, KPI provided are indicative and not intended to be a measure of the efficiency of the solutions.

For each level of automation being assessed using the XAI and VA components, the validation will consider the following arguments related to the TAPAS concept for the ATFCM scenarios:

Human Performance ***The focus is on the ability to understand what the automation is doing and why, as well as the level of situational awareness and trust in the system of the human operator, at varying levels of automation***
1.1: The roles and responsibilities of the human operators are clear and exhaustive at each level of automation being considered

1.2: Operational methods and procedures employed at each level of automation are sufficient and complete in order to achieve the Demand-Capacity Management tasks required in the pre-Tactical phase

1.3: At low levels of automation (Level 1):

The information being provided by the VA support tools provides suitable information and analytic views to allow the human to fully understand the solutions that are being proposed and to make an informed choice on which proposed action to perform

1.4: At medium levels of automation (Level 2):

The information being provided by the VA support tools provides suitable amount of information and analytic views to allow the human to fully understand the solutions that are being proposed by the system to solve the existing hotspots.

1.5: At higher levels of automation (Level 3):

The information that is provided by the support tools has appropriate information and analytic views to allow the human to fully understand the solutions that are being automatically implemented.

Reasons why those choices were made are clear and the human understands the solutions and the reasoning behind them.

The human is also able to confirm that the decisions applied are suitable for the problems being solved.

1.6: (*Optional if time and the platform permits*):

In the case of a failure of the automation support at any level of automation, the human operator is able to take over the demand capacity management process and complete it successfully without further use of the automation tools / VA support

Efficiency

Although the main focus of the TAPAS validation is on transparency and understanding of solutions being proposed by XAI automation support tools, to help in developing trust and acceptance of those tools, the solutions should have a realistic level of performance.

1.1: Efficiency metrics used in the TAPAS validation are there to ensure that the solutions being proposed by the XAI components can be considered as 'fit for purpose'. For example, a '*truth-matrix*' can be used to evaluate the efficiency of the XAI in identifying Hotspots correctly.

The objective of the XAI tools is not to create a solution that is necessarily '*better*' than would have been achieved without the tool in place. Nevertheless, if solutions are not fit for purpose, then the operator would not be in a position to accept them and trust in the approach would be difficult to achieve.

1.2: The number of flights impacted due to proposed solutions being provided by the XAI support tools is similar or fewer than the number that would be impacted without the tool in place.
1.3: Delays to traffic and on-time arrival statistics are not adversely impacted due to the use of the XAI tools at varying levels of automation
1.4: The human operator is able to confirm that the solutions being proposed (Level 1) or which have been partially or fully implemented (Levels 2 & 3) are acceptable solutions that might also have been used if the automation was not present. Note: that this does not imply that the human operator needs to confirm that these are the '*best*' solutions available, merely that those solutions are acceptable.
1.5: The workload on the human operator is decreased as the level of automation increases
1.6: Impacts to traffic are distributed across various airspace users in an equitable manner.
1.7: (*Optional if time and the platform permits*) In the case of a failure of the automation support at any level of automation, the human operator should be able to create their own solutions manually which align with the 5 efficiency arguments stated above

Safety ***Safety is not a primary driver in the ATFCM process, particularly as the tasks being assessed are in the pre-Tactical management phase. Overloads remaining at the end of the process may be used as a proxy for 'safety' however. Nevertheless, some safety criteria are included to ensure the solutions are not making the system less safe.***
1.1: When the set of solutions being proposed by the XAI automation have been completely implemented, few or no areas of overload remain which may impact safety during the execution phase
1.2: At any time during the execution of the scenario and for any level of automation, the human operator is able to explain what is happening and why, if asked. Failure to maintain this situational awareness represents a potential safety concern.
1.2 (Optional if time permits): In the case that a failure of the automation support occurs at any level of automation and at any time, the human operator is able to take over and complete the exercise with no further use of the automation support. Failure to be able to complete the process in the event of automation failure represents a safety concern.

4.1 ATFCM Exercises Description and scope

The ATFCM validation is focused on Demand-Capacity Management within the continental Spanish airspace.

Exercises will use daily samples of planned traffic data taken from archives maintained by ENAIRE/CRIDA and EUROCONTROL and will focus on the management of Demand and Capacity for the region in the pre-Tactical (D-1) phase.

4.2 ATFCM Validation Assumptions

The following assumptions have been made with regard to the ATFCM validation exercises:

- The main assumptions are the repartition of the tasks at each level of automation between the human operator and the automation tools is done as previously described (see Section 3.2.3).
- Additionally, it is assumed that the human operators involved in the execution of the validation experiments are fully familiar with the NM Pre-Tactical planning and Demand-Capacity Balancing process.
- It is also assumed that sufficient training/briefing has been provided to the human operator in regard to the scenario and available tools to ensure that any lack of familiarity with the working environment is not a negative factor in the understanding or acceptance of the solutions being proposed.
- The operational scenario is modelled in a realistic environment using a validation platform (INNOVE) that supports all of the B2B ATFCM planning services available from NM.
- XAI components have been suitably trained using historic datasets for the analysis region.
- Data that is used for the validation exercises is unseen data that has not been previously included as part of the XAI training datasets, that is, to avoid overfitting of the algorithms. This is the main criterion on the XAI training, together with the selection of a large amount of data to conform a representative sample. In particular, for this ATFCM use case, the whole year 2019 regulations and flights data was provided to train the XAI algorithm, but final training data was focused on AIRAC1908. Therefore, different days of the previous AIRAC 1907 were the ones selected for the validation scenarios. For a more detailed description on the training process please refer to the D4.1 TAPAS Integrated Prototype deliverable [10] [13]13].
- The XAI component is integrated (loosely) with the validation platform and uses the same scenario data (environment, capacity, traffic demand etc.) as the emulated ATFCM environment.
- A prototype FMP client position is available to provide the human operator with features that are similar to those available in the real operational environment.
- A co-located visual analytics and explanation display is included with the FMP position.

- VA components are able to consume data from the XAI automation component to provide suitable visual and information and scenario drill down functionality

4.3 ATFCM Validation Infrastructure

The validation experiments will be carried out using the INNOVE simulation platform. INNOVE is capable of simulating all the NM B2B ATFCM planning services required for the pre-Tactical demand capacity management activity.

As no working position was readily available for use in the project, a prototype FMP Working Position (FMP Client) has been developed to support the operational user. This working position offers most of the same functions that are available in operational FMP tools.

The FMP client will also be adapted to enable it to consume data related to the presentation of traffic demand, identification of Hotspots, and proposed ATFCM solutions that are produced by the XAI components.

The co-located VA display included in the FMP working position is used to present the Visual Analytics and explanatory support information. The information provided using this viewer has been specifically designed to assist the user in the understanding of the automation decisions.

The INNOVE network simulation and the XAI components use common traffic and operating environment data during the execution of the validation scenario.

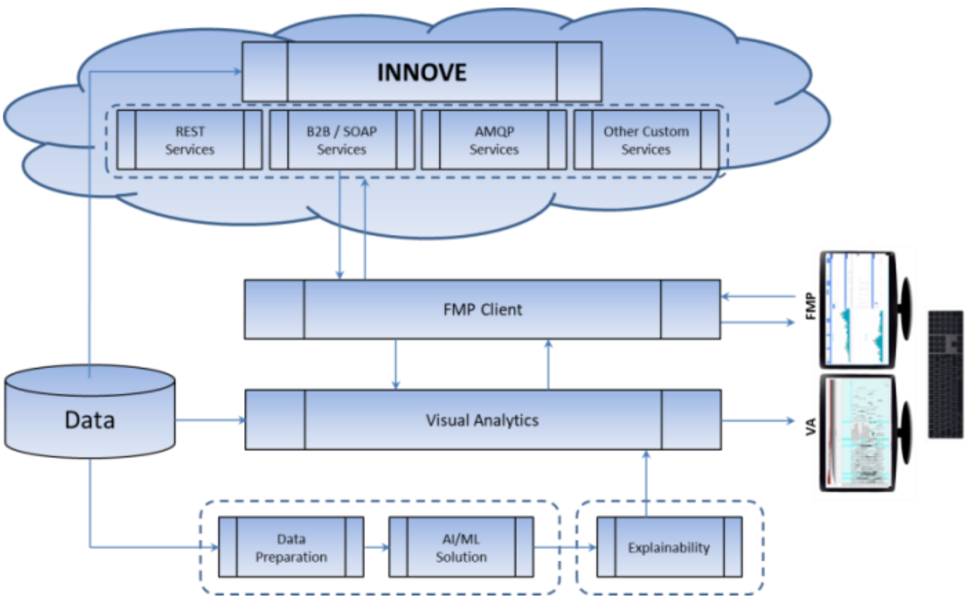


Figure 2: ATFCM Validation Infrastructure

The FMP client is implemented to be an operational tool which can both display the current network situation and allow the user to input new ATFCM actions (e.g., ATFCM regulations or re-routing measures) into the INNOVE simulation.

Functionality that can be used by the LTM/FMP user will be adapted in accordance with the level of automation being simulated to:

- Provide sector / traffic volume load and occupancy charts for any of the ACC in the region
- Support interactive consultation of traffic lists for the flights which make up any of the charted periods
- Identify overloads on the load/occupancy charts, compared to the declared capacity thresholds that were provided by ANSP for the AIRAC cycle
- Display information about hotspots identified by the XAI tool
- Allow users to create the same hotspots in INNOVE via the FMP client interface
- Automatically create Hotspots in the INNOVE environment based on data received from the XAI component
    - Without user intervention
- Display proposed solutions to traffic for each Hotspot
    - Delay only
    - FLC only
    - Delay and FLC combined
- Allow users to create a SIMULATION (what-if 'sandbox' environment) in the INNOVE scenario
- Allow users to create regulations or measures to apply with the proposed solutions in the INNOVE platform
    - In a SIMULATED 'sandbox' environment to support what-if analysis, or
    - In the OPERATIONAL environment to create the actual measure(s)
- Automatically create measures in the INNOVE scenario using data provided by the XAI component
    - In a SIMULATED 'sandbox' environment to support what-if analysis, or
    - In the OPERATIONAL environment to automatically create the actual solutions
- Perform analysis of the network impact of the implemented/simulated measures
- Record information to support post validation analysis and metrics generation

The experimental VA support information will be displayed on a second screen that is co-located with the FMP working position.

The VA interface provides interactive graphical support to assist the user in developing a clear understanding of the criteria and features that have been considered by the XAI automation during the decision-making process by exploring the data, including:

- Analysis of the DCB scenarios being analysed by the AI components
- Visual summaries for the variants of solutions
- Display of the evolution of the solutions over iteration steps of the simulation process
- Provision of details for each hotspot, sector, and time interval, including aggregated information about the flight delays
- Support for on demand: features that justified delay decisions for selected flights, sectors, and time periods
- Display of further relevant information, to be selected in collaboration with project partners.

The data that is supported on the VA screen will also be tailored according to the level of automation being emulated in the scenario including:

- Exploration of baseline scenarios with Hotspots identified but no solutions implemented
- Exploration of scenarios for delay-based solutions only
- Exploration of scenarios for flight level capping solutions only
- Exploration of scenarios for combined delay and flight level capping solutions

4.4 ATFCM Validation Levels of Automation

Specific exercises that emulate different levels of automation are planned for the ATFCM validation experiment.

In the Level 1 exercise, the automation will identify DCB issues and provide information related to hotspots, but no recommendations on how to solve the issues will be provided.

The Level 2 exercises will use the automation to identify hotspots and declare them in INNOVE, as well as to provide some solutions based on either Regulation or Reroute using Flight Level capping. The human will still be involved in the implementation of the proposed measures, being able to determine the impact and suitability of the proposed solutions using the SIMULATION dataset. This will allow the operational user to interrogate those solutions to determine if they are suitable for implementation.

For the Level 3 exercise, proposed solutions being produced by the AI DST will be automatically notified to INNOVE and implemented accordingly, using the OPERATIONAL dataset. At Level 3, solutions may be based on Regulations, Flight Level Capping or a combination of both.

4.5 ATFCM Validation Scenario(s)

4.5.1 ATFCM Analysis Region

The analysis will be based in the continental Spanish airspace, focusing on the Madrid ACC, using archive data provided by ENAIRE/CRIDA and EUROCONTROL. ATFCM regulations and measures that may apply to traffic due to demand-capacity issues in other regions will not be included for the purpose of the TAPAS validation experiments.

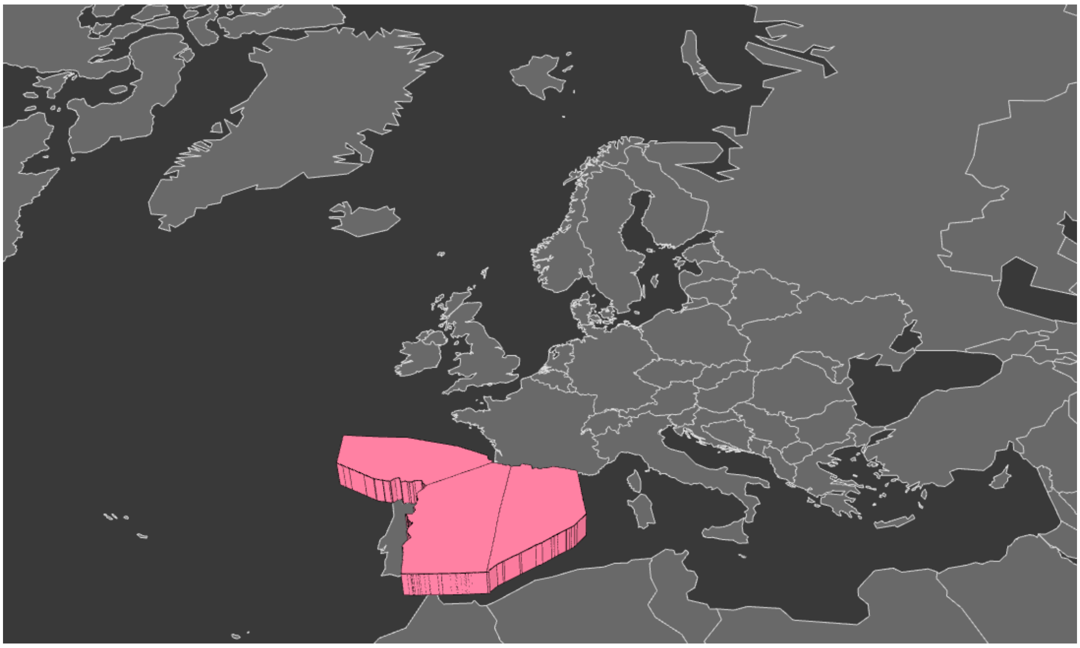


Figure 3: Simulated Region

While the XAI components will attempt to identify issues across the entire region and propose solutions and flights which should be included in the resulting measures, the operational FMP position and VA support components will be configure to a single ACC in the region. This is to ensure that the operating environment for the LTM/FMP is consistent with the current working environment.

4.5.2 ATFCM Analysis Traffic

Traffic will be extracted for the Spanish airspace region from the ENAIRE/CRIDA/EUROCONTROL data archives. Each of the simulation exercises will be performed using a representative traffic sample for a single one-day period and includes all traffic that departs from or arrives at airports in the region, as well as all over flights.

Traffic data is supplied in the DDR2 ALLFT+ V5 format and includes information related to filed (FTFM), regulated (RTFM) and executed flight plans (CTFM) for the entire trajectory of each flight that was planned to operate on the selected date.

This data is used to populate the INNOVE simulation scenario as well as to support the XAI automation and decision-making components. The data is also available for use in the VA visualisation components if required.

Traffic data to be used for the validation exercises will be selected from dates that have not been used previously to help train the AI/ML Decision Support components.

In reality, to support the training process for the ML-based ATFCM automation component, a full year of traffic data was made available (for 2019). However, the main training focused on a single month of data that was associated with the Aug 2019 AIRAC cycle (AIRAC 1908).

4.5.3 ATFCM Operating Environment Data

Data to describe the ATFCM operating environment is extracted from the ENAIRE/CRIDA/EUROCONTROL data archives and is provided in DDR2 format. The data used is from the same AIRAC cycle as the selected traffic samples.

For the training process, the AIRAC 1908 data has been used. Hence to support the execution phase one of the adjacent AIRAC cycles will be used (e.g., AIRAC 1907 from July 2019) – this will help to ensure that there are no 'major' differences in the operating environment since they are only 1-month apart and part of the summer period, so should therefore have similar configurations.

The environment data includes information about the available sector configurations that can be used for different ACC during the operational day, as well as the opening schedule that was planned for each day in the AIRAC cycle. As the XAI component uses this schedule to support traffic demand calculations, the schedule will be considered as being fixed for each scenario (i.e., the FMP/LTM are not permitted to modify the sector configuration plan using the available B2B services).

Environment data also provides the airspace capacity plan, expressed for both Traffic Demand and Occupancy (peak and sustained) metrics. Capacity plans are also defined according to a proposed schedule and can vary at different times of the day, as well as in relation to the sector configuration that is active at any time. These may also be adapted at any time by the LTM/FMP using the associated B2B capacity plan update services. However, as the XAI components are taking decisions based on the capacity and configuration plans provided in the original environment data, the capacity plans will also be considered as fixed for the scope of the validation exercises.

4.6 ATFCM Analysis Validation Exercises

The ATFCM validation will involve operational staff from ENAIRE with experience in Pre-Tactical capacity planning activities. They will work in the simulated environment to perform Demand Capacity balancing tasks. Feedback on the tools used to support the process at different emulated levels of automation will be gathered and as input for further analysis to elaborate the basic principles for transparency.

To extract operation experts' input, the project will use questionnaires, over-the-shoulder observation and debriefing to collect the experts' opinion. The questionnaires will have a mixture of score-based questions (e.g., regular scoring of workload/understanding such as NASA-TLX or the Bedford Scale, situation awareness – SASHA and trust in automation - SATI) together with open-ended questions to provide opinion on the situation. These will be analysed independently.

Additionally, to support other quantitative metrics, output data will be recorded from the validation-platform to support post processing analysis. This will include data relating to the Hotspots that were identified, FMP actions that were performed using the platform, XAI solutions that were proposed and/or automatically implemented and a range of metrics relating the impact on the proposed flight plans on the Air Traffic Network in the Spanish airspace region.

In support of the ATFCM validation exercises, three main scenarios are foreseen. These will be executed to emulate each of the levels of automation described previously in this document

This section provides details of each of the proposed experiments.

4.6.1 ATFCM Scenario #1 – Level 1 Automation

4.6.1.1 Description & Scope

The initial scenario will be executed with DST support functions operating at automation level 1. At this level, only the Traffic Demand Monitoring and Imbalance Identification functions are performed by the machine. All other functions are performed by the human operator based on the information that is provided from the DST.

The scenario will be primarily used to verify demand capacity issues (Hotspots) that are identified by the XAI components are consistent with issues that are identified by the operational user using the FMP client application working against data contained in the INNOVE network manager simulation platform. The scenario will also help to familiarise the user with the various features of the prototype FMP position and supporting VA information display components.

A limited set of Visual analytic features will be used to support the analysis of the traffic demand scenarios, and interactive exploration of sector and demand scenarios.

Hotspots identified by the XAI tool will be added to the INNOVE scenario by the LTM/FMP operator using the FMP client interface and associated B2B services. This will facilitate comparative analysis of the flights that are concerned by the various hotspots that have been identified.

Assuming the analysis of the imbalances that are detected is considered acceptable, the LTM/FMP operator can prepare suitable DCB measures using the FMP client interface, create a SIMULATION environment and implement the measures to evaluate the suitability of solutions.

4.6.1.2 Expectations

Hotspots that are identified by the XAI are also able to be identified in the simulated NM environment managed by INNOVE.

A truth matrix capturing the conformance of the XAI in comparison to the simulated NM environment will be created to capture the levels of conformance of the imbalance identification functions to identify areas where hotspots are correctly identified in both tools, areas where there are no hotspots are correctly identified by both tools and differences between the tools are captured.

For hotspots that are common to both tools, lists of concerned flights will be compared and contrasted.

The human operator is able to consult the VA components to understand why the XAI has identified hotspots and can create regulations and/or rerouting measures (in INNOVE) to help solve those issues.

4.6.1.3 Objectives

The objective of the automation level 1 is twofold. Firstly, the aim is to validate the set of imbalances identified by the XAI tools for the scenario and secondly, to allow the operational user to investigate how and why they have been found using the associated VA components.

XAI traffic demand profiles will be compared with those provided from INNOVE and the sets of flights that are included in hotspot areas can be compared and contrasted.

4.6.1.4 Scenarios

Suitable data from the ENAIRE archives will be selected to create the validation scenario. This will use a single day of traffic from the July 2019 (1907) AIRAC cycle and the corresponding DDR2 environment data.

Traffic loads using hourly entries and a sliding 20-min window will be evaluated by the XAI component and hotspot areas identified for the currently active airspace configuration(s) using the corresponding demand thresholds.

Results from the XAI analysis will be provided to the VA component to support the exploration of sector and traffic demand characteristics as well as the identified hotspots.

No solutions are provided to the user at automation level 1 therefore VA components related to the exploration of solutions are not supported in this scenario.

The FMP client is able to provide on-demand sector load and occupancy metrics for the scenario, and highlights issues that are identified, based on the configuration and capacity plans that have been loaded into the platform.

Using on-demand SIMULATION datasets, hotspots identified by the XAI can be added to the SIMULATION instance by the user to allow the FMP user to obtain additional data (e.g., flight lists).

Regulations and reroutes can be created through the FMP client interface to evaluate solutions to the identified problems.

4.6.1.5 Assumptions and Limitations

As the XAI and INNOVE tools include their own trajectory and traffic demand generation features that operate independently, some minor differences may be observed between the two systems. Nonetheless, it is assumed that the conformance for key indicators such as sector demand metrics, flight lists, hotspot locations and hotspot start/end times should have a close correlation.

As scenario #1 remains at a very low level of automation, most of the more advanced VA features will not be used in support of this scenario, and comparisons will be performed by the operational user via the FMP client interfaces.

4.6.2 ATFCM Scenario #2 – Level 2 Automation

4.6.2.1 Description & Scope

Scenario #2 will focus on use of the XAI decision support tools at Level 2 automation. At this level, many of the tasks are performed automatically by the XAI support tools and the user is able to consult the VA display components to navigate through problems that have been identified and solutions that are being proposed.

In scenario #2 the XAI will provide full traffic demand monitoring, identification of imbalances and the corresponding hotspot information. The human is still involved in the declaration of hotspots in the simulation environment (INNOVE) but details of hotspots can be automatically included in the B2B hotspot plan update function if required.

The XAI will also determine suitable sets of solutions based on either Regulations only or Flight Level Cap actions and will propose them to the operational user. These proposals can be investigated further to help ensure transparency using the VA solution explorer components and additional drill down information can be accessed via the sector explorer.

Proposals that are considered as suitable solutions to the detected issues are created by the human and sent to the simulated NM environment (in either the OPERATIONAL dataset – if they are to be implemented, or in an on-demand SIMULATION instance) via the B2B services supported through the FMP client interface.

Monitoring of the impact of the solutions is supported through the FMP working position.

4.6.2.2 Expectations

At automation level 2 it is anticipated that the majority of the decision-making process is being performed by the XAI DST, and that the operational user, having gained confidence in the hotspot identification process during scenario #1, is able to see and review solutions that are being proposed.

The human will have access to the full set of VA support tools to allow them to investigate the solution set and to understand why the XAI has proposed these actions, including the ability to capture which traffic will be impacted by the proposed action and why. The human will also have access to additional graphical support tools that illustrate the steps in the process by which solutions have been reached and the overall impacts of different solutions.

Using the information available in the FMP client and the VA support components, the human is able to make informed judgement on the most appropriate measures to apply to respond to the imbalances.

Having made the decision, the human is still involved in the creation of the corresponding measures which will be added in the simulated NM environment through the functions provided in the FMP client interface.

Impacts of the implemented measures, and any remaining hotspots can be analysed either interactively using the FMP working position or as a post processing activity.

4.6.2.3 Objectives

The objective of scenario #2 is to allow the XAI components to both identify areas of imbalance, automatically declare hotspots to the system, and to provide sets of solutions that can be used to help resolve those issues.

At automation level 2, the human is still involved in the review and selection of the actions that should be implemented, and to ensure that this can be done with a good knowledge of what is happening in the scenario, and how solutions have been identified, advanced VA components are provided.

The main objective is to evaluate how these VA components are able to provide key information to the operator, whether that information is able to foster a good understanding of what is being proposed, and if the user can maintain a sufficient picture of what the solutions offer, and why. Additionally, the user should be capable of distinguishing between different potential solutions, and with the help of the VA features, to select the most appropriate ones for implementation.

4.6.2.4 Scenarios

Specific details of the scenario will be provided as the preparation of the experiment progresses. As with the previous scenario, traffic, and operating environment data from an appropriate sample date for the same (1907) AIRAC cycle will be used to generate the scenario.

XAI components will be run using the scenario data to produce both the set of hotspots that need to be solved for the scenario as well as potential solutions that could be applied to resolve the issues.

Hotspots are automatically declared in the simulated NM environment, but the human remains in the loop when reviewing the potential actions and deciding which, if any should be implemented.

The human remains responsible for the creation and implementation of the selected measures, which will be performed using the available B2B service interfaces in the FMP client.

4.6.2.5 Assumptions and Limitations

Scenario #2 assumes that the human has developed a sufficient level of confidence in the XAI support tool to allow hotspots to be automatically notified in the system, and to allow the XAI components to assess potential solutions.

It is also assumed that, when needed, the human operator is able to explore the proposed solutions using the corresponding VA functionality to obtain a good overview of problem scenarios, to make comparisons between different proposals and to track the steps that were carried out to arrive at the various solutions.

The user should also be able to follow how the development of any given solution has identified and modified flight plans as it works towards the objective of solving the known issues. Additionally, the user should also be able to use the VA support to identify situations where solutions result in a knock-on effect, e.g., creating new hotspots in different areas as a result of a proposed action.

It is also assumed that the human is able to consult the hotspots that have been automatically identified by the DST and to understand how the proposed solutions intend to manage those issues and why.

4.6.3 ATFCM Scenario #3 – Level 3 Automation

4.6.3.1 Description & Scope

Scenario #3 will execute the same processes as those used in scenario #2 with the exception that when feasible, the most appropriate solutions will be automatically applied and implemented in the simulated NM environment.

The human in still involved in the process but takes on more of a monitoring role, potentially being required to ‘confirm’ that the proposed action is implemented, to maintain awareness that these actions are being taken by the system, but not being given an option to modify or refuse them.

In this scenario the focus is heavily on how the VA support tools can be used by the human to help to understand what problems are being solved, which solutions have been identified and why. Particular importance should be given to the evaluation of the situational awareness of the human, to ensure that they remain fully aware of what is happening during the process.

4.6.3.2 Expectations

While monitoring the situation, the human should be capable of understanding which problems are being considered and why.

The human operator should also be fully aware of the solutions that have been identified and when they are implemented, but no specific action is required on their part.

The human is able to respond to the evolving situation and consult the VA components to investigate how the DCB scenario is evolving without intervening in the on-going process.

If asked, the human is able to identify the problems that are being solved and to describe the solutions that are being developed and why they are appropriate in resolving the situation.

4.6.3.3 Objectives

The objective of scenario #3 is to provide the XAI components with full freedom to identify areas of imbalance, automatically declare hotspots to the system, and determine suitable responses from the sets of solutions that could be used to help resolve those issues.

The human is only involved in a monitoring role, and to ensure that they remain aware of what is happening in the scenario, and how solutions have been identified, advanced VA components are provided.

The main objective is to evaluate how these VA components are able to provide key information to the operator to ensure a good understanding of what has been proposed and implemented.

The user must be able to maintain a sufficient picture of what issues have been addressed, how they have been solved and why.

Additionally, the user should be capable of reviewing alternative potential solutions, and with the help of the VA features, to help to assess whether the solutions that were actually implemented were the most appropriate.

Users are also able to analyse the impact of the implemented solutions to ensure that the issues have been solved, and to act upon any remaining problems that require their action.

4.6.3.4 Scenarios

As with the previous scenarios, traffic, and operating environment data from an appropriate sample date for the same (1907) AIRAC cycle will be used to generate the scenario.

XAI components will be run using the scenario data to identify the set of hotspots that need to be solved for the scenario and sets of potential solutions that could be applied to resolve those issues.

Hotspots are automatically declared in the simulated NM environment, and the XAI automation is able to select the most suitable solution from the available set and implement it in the simulated NM environment.

Depending on the ability of the platform, and to help ensure the human is aware of the different processes, the platform may be adapted to require the human to ‘confirm’ that automated actions are applied (but will not be given the possibility to refuse or modify those actions).

The human only provides a monitoring role but can investigate solutions that have been created using the VA support components and to follow the process steps that led to any particular action(s).

If any issues remain at the ‘end’ of the XAI process, the human can use the functionality provided in the FMP working position to resolve them if needed.

4.6.3.5 Assumptions and Limitations

Scenario #3 lets the XAI support tools identify hotspots, automatically notify then in the system, and to identify and select potential solutions. The system also implements these actions automatically.

It is assumed that the system is able to indicate to the human operator that is acting in a monitoring role when the different operations have occurred. Nevertheless, additional visual cues (e.g., a need to confirm that a solution can be implemented) may be included to help maintain awareness of what is being implemented and when.

It is also assumed that the human operator is able to explore the proposed solutions at any time during the process using the corresponding VA functionality. This should allow them to maintain a good overview of problem scenarios, to make comparisons between different proposals and to track the steps that have been performed leading up to and executing the proposed solutions.

The user should also be able to follow how the development of any given solution has identified and modified flight plans as it works towards the objective of solving the known issues. Additionally, the user should also be able to use the VA support to identify situations where solutions result in a knock-on effect, e.g., creating new hotspots in different areas as a result of a proposed action.

It is also assumed that the human is able to consult the hotspots that have been automatically identified by the DST and to understand how the proposed solutions intend to manage those issues and why.

In the event of any remaining issues or system failure / corruption, it is assumed that the human will need to resolve these manually to complete the process using the available features in the FMP working position.

5 ATC-CD&R Validation Activities

This section describes the validation scenarios and experiments that will be performed in the ATC-CD&R domain to help to assess the impact or success of the introduction of AI-based automation and decision support systems with varying levels of automation and the ability for human operational experts to understand what is being proposed and why. As the levels of automation increase across different scenarios, analysis of the transparency of proposed solutions will be assessed, as well as the level of operator trust in the tools.

The main aim of the CD&R validation is to analyse how the XAI components can support the automated detection and resolution of conflict situations in an active ATC sector that is being controlled by a classical combination of a Planner and an Executive (Radar) controller. Additionally, the response to challenges related to the provision of suitable explanatory information and associated VA features when the automation is running with very short timescales and at high levels of safety will be assessed – in particular looking at how the human can interact with those tools in a safety and time critical environment.

From the transparency perspective, the objective is to determine whether these components are able to inform the operators to a sufficient degree that allows them to understand the solutions being proposed and why, in a very short timeframe. In addition, it is important to ensure that the solutions provided are also able to solve the issues identified in good time and with appropriate actions that are acceptable to the Controllers who are working the sector.

As part of the analysis, the validation experiments will also attempt to measure the levels of situational awareness that the human operators are able to achieve in various scenarios. If time permits, this may also include randomly allowing the automation to fail – in which case the ATC operators will be required to recover the situation and solve issues themselves without the help of the automation.

As it is also planned to include a conformance monitoring component within the XAI tools, controllers will also be asked to determine whether the proposed actions are being correctly implemented by the effected traffic, or not, and to confirm that the actions are suitable in response to the identified issues. In particular, the conformance monitoring functionalities will be provided by the XAI tool only in accordance with the proposed solution, that is, for automation level 2 and 3 the XAI after proposing a resolution action for a certain conflict will monitor the new updated trajectories to see if the updated trajectories follow the solution provided.

The analysis will also consider the following Key Performance Areas:

- Human Performance
- Flight Efficiency
- Safety

As for the ATFCM scenario, the TRL for the proposed CD&R XAI support components is a low level (TRL 1). Hence the automation prototypes that are being developed are not intended for deployment and testing of mitigation actions that are expected to be available will be limited.

The focus of the validation will be on analysis of how the explanatory support features are able to support and promote human understanding, situational awareness and whether such tools are able to provide the correct levels of information in the required time to ensure that the system remains safe and efficient when automation is active. For these reasons the KPI are provided for information purposes only and are not intended to assess the efficiency of the solutions proposed by the AI component.

For each level of automation being assessed using the XAI and VA components, the CD&R validation will consider similar arguments to those that were examined for the ATFCM scenarios. However more focus on on-time performance and safety criteria will be included:

Human Performance

The focus is on the ability to understand what the automation is doing and why, as well as the level of situational awareness and trust in the system of the human operator, at varying levels of automation. Additionally, the operators should be able to understand the explanatory information rapidly in order to react in a timely and safe manner to all issues that have been identified.

1.1: The roles and responsibilities of the human operators are clear and exhaustive at each level of automation being considered

1.2: Operational methods and procedures employed at each level of automation are sufficient and complete in order to achieve the Conflict management tasks required to ensure safe separation between aircraft and to propose efficient and acceptable mitigation actions in a timely fashion

1.3: At low levels of automation (Level 1):

The information being provided by the VA support tools provides suitable information and analytic views to allow the human to fully understand the conflicts that have been identified and to make an informed choice on how to solve them. For automation level 1 only the detection of the conflicts is supported automatically, no proposed solutions will be provided to the ATCO at this automation level (see section 3.2.5 for more detailed information on CD&R automation allocation). Nonetheless, the information provided by the VA on this detections, as well as the available information on the ATC platform, should be sufficient data for the operator to design and implement a satisfactory resolution action (note that current operations are already running at automation level 1 and in some cases higher since STCA and MTCD systems are available to assist in conflict identification – for this reason only a few exercises will be performed at this level of automation – mainly to help validate the conflict detection component(s) of the XAI).

Additionally, the alerting when a conflict is provided to the ATC operator a sufficient time in advance of the problem to allow them to determine a suitable resolution action.

1.4: At medium levels of automation (Level 2):

The information being provided by the VA support tools provides suitable amount of information and analytic views to allow the human to fully understand the solutions that are being proposed by the system to solve the conflicts that have been identified by the system and to make an informed choice whether to apply the proposed solution or reject it in favour of an alternative developed by the ATC operator.

First of all, the ATCOs need to understand what it is being proposed (specific actions) so they can know the proposed resolutions actions and apply them themselves. And secondly, they need to understand why that specific action is being proposed and no other (e.g.: the reasons behind proposing a specific type of resolution action, change of heading, change of speed, and no other, reasons may vary and could include, for instance, motives such as minimise the number of impacted flights later on, etc.).

Identification of separation issues and provision of a proposed action should be done with a sufficient time to allow the operator to make an informed decision.

1.5: At higher levels of automation (Level 3):

The information that is provided by the support tools has appropriate information and analytic views to allow the human to fully understand the solutions that are being automatically implemented.

Reasons why those choices were made are clear and the human understands the solutions and the reasoning behind them.

The required level of understanding achieved using the VA support is able to be attained in a suitable timeframe to allow the human to maintain a high level of situational awareness with regard to the action that have been taken and allows them to monitor that the proposed actions are suitable for solving the problem.

The human is also able to confirm that those decisions are suitable and safe.

1.6: (*Optional if time and the platform permits*):

In the case of a failure of the automation support at any level of automation, the human operator is able to take over the separation management process and complete it successfully without further use of the automation tools / VA support.

Efficiency

Although the main focus of the TAPAS validation is on transparency and understanding of solutions being proposed by XAI automation support tools, to help in developing trust and acceptance of those tools, the solutions should have a realistic level of performance. In particular metrics such as penalties to traffic expressed in terms of increase path length, flight level penalties or delays can be considered.

1.1: Efficiency metrics used in the TAPAS validation are there to ensure that the solutions being proposed by the XAI components can be considered as 'fit for purpose'. For example, the set of conflicts that have been identified by the XAI can be compared to those captured using other tools, and the time offset ('time to conflict') could be used to determine whether the issues are identified with sufficient time to allow users or automation to determine suitable mitigation actions and apply them.

The objective of the XAI tools is not to create a solution that is necessarily '*better*' than would have been achieved without the tool in place. Nevertheless, if solutions are not "fit for purpose" then the operator would not be in a position to accept them and trust in the approach would be difficult to achieve.

1.2: The number of flights impacted due to proposed solutions being provided by the XAI support tools is similar or fewer than the number that would be impacted without the tool in place.

1.3: Sector exit delays to traffic, sector path length extension, flight level penalties, and separations achieved are not adversely impacted due to the use of the XAI tools at varying levels of automation

1.4: The human operator is able to confirm that the solutions being proposed, or which have been partially or fully implemented (Levels 2 & 3) are acceptable solutions that might also have been used if the automation was not present. The human also has sufficient time before the start of the conflict to review and understand the problem and if required propose a solution/review a proposed action with sufficient time remaining to implement it.

Note: that this does not imply that the human operator needs to confirm that these are the '*best*' solutions available, merely that those solutions are acceptable.

1.5: The workload on the human operator is decreased as the level of automation increases

1.6: (*Optional if time and the platform permits*)

In the case of a failure of the automation support at any level of automation, the human operator should be able to create their own solutions manually which align with the 5 efficiency arguments stated above

Safety

Unlike the ATFCM scenario, when deploying automation to support the CD&R process, safety and on-time performance is a critical indicator – even at a low TRL.

In particular, all of the identified conflicts should be successfully solved and proposed actions should not result in any new conflicts. Similarly, the time to conflict indicator is used to determine how much time the operator has available to review and/or solve each issue as CD&R is a time-critical activity and under normal situations, conflicts are resolved between up to 10-minutes in advance (and not 'at the last possible moment')

Other measures such as closest distance between flights (after action is taken) and any remaining separation infringements (and their criticality) should also be used to support the analysis of safety performance indicators.

Additional conformance monitoring indicators will be used to ensure that the XAI solutions have been correctly implemented and XAI conformance monitoring indicators will be recorded for post operations analysis

1.1: When the solutions being proposed by the XAI automation have been completely implemented, no conflicts remain which may impact safety
1.2: When proposed solutions are accepted by the operator, the separation minima distances between flights are respected.
1.3 Conflict alerts are produced in sufficient time to allow the user/automation to determine and implement any required/proposed action
1.4 Time to conflict indicators will be analysed to determine whether the human has had sufficient time to develop an understanding of the situation and has the opportunity to determine a suitable action, or to evaluate that a proposed action is feasible and can be applied.
1.5 Analysis of final flight trajectories will be carried out to ensure that no separation losses remain after each scenario – the presence and criticality of any remaining issue will help to provide a safety performance indicators for the various scenarios
1.6 Monitoring of the conformance of resolved flights with respect to the proposed action will be performed during the simulation and reviewed in post simulation analysis. Non-conformance alerts, if provided by the XAI or other tools, will be analysed to determine their potential safety impact
1.7: At any time during the execution of the scenario and for any level of automation, the human operator is able to explain what is happening and why, if asked. Failure to maintain this situational awareness represents a potential safety concern.
1.8 (Optional if time permits): In the case that a failure of the automation support occurs at any level of automation and at any time, the human operator is able to take over and complete the exercise with no further use of the automation support. Failure to be able to complete the process in the event of automation failure represents a safety concern.

5.1 ATC-CD&R Exercises Description and scope

TAPAS project will develop an XAI CD&R prototype, together with the appropriate VA techniques, containing functionality to monitor the current situation, detect possible conflicts, propose resolution measures for those conflicts and, for automation level 3, implement said solutions automatically.

Using this prototype, different real-time simulations will be performed within TAPAS project framework. The validation activities will involve ATC-platforms and licensed air traffic controllers from ENAIRE and PANSA that will act as executive controllers, in order to derive general principles of transparency for the different levels of automation, which is TAPAS main objective to perform this proof of concept rather than the development of any operational software.

The main objective of the validation exercises regarding the CD&R use case is to validate through Human In The Loop (HITL) validation techniques the AI/ML capabilities to support the introduction of greater levels of automation into the ACTO CD&R tasks for the different automation levels considered, providing results and evidence for further analysis and derivation of explainable principles. Therefore, the outcomes obtained will be both qualitative and quantitative.

In particular with the use of VA components, one of the principal goals is to collect feedback, concerning the visualisation designs and interactive techniques, including which are the most appropriated methods to use, any suggestions for improvement, which are the key features that need to be provided to the operator, if there is something missing or if the information is excessive, etc. All of these will help obtain useful guidance for directing further developments of visual interfaces to XAI.

5.2 ATC-CD&R Validation Assumptions

For the CD&R use-case, since the focus will be on the timely provision of automated solutions and the need to get users to comprehend solutions being proposed in short time-frames, as well as to allow them to be capable of understanding the issues being resolved and the reasons why those solutions have been selected, the VA and associated explanatory components will need to provide succinct and easy to comprehend information to the operational users.

To address this overriding constraint several specific assumptions have been made for the CD&R simulation case:

- The division of the tasks at each level of automation between the human operator and the automation tools is done as previously described (see Section 3.2.4).
- Additionally, it is assumed that the human operators involved in the execution of the validation experiments are fully familiar with the ATC Sector Executive controller activities.
- It is also assumed that sufficient training/briefing has been provided to the human operator for the scenario and the available tools to ensure that any lack of familiarity with the working environment is not a negative factor in the understanding or acceptance of the solutions being proposed. However, as the simulator platform is the same as the CWP that is used in daily operation in the Spanish ANSP, it is assumed that the operators are already very familiar with all the features of the system except for the XAI and VA support tools.
- The operational scenario is modelled in a realistic environment using a validation platform (SACTA) that supports the needed ANSP ATC working tools and methods that are available in the current ATC systems.
- XAI components have been suitably trained using historic datasets.
- Data that is used for the validation exercises is unseen data that has not been previously included as part of the XAI training datasets, that is, to avoid overfitting of the algorithms. This is the main criterion on the XAI training, together with the selection of a large amount of data to guarantee a representative sample. In particular for this CD&R use case, a whole year of 2019 radar tracks, flight plans and ATC events data for Barcelona ACC sectors was provided to

train the XAI algorithm. To ensure that unseen data was used for the HITL experiments, Madrid ACC enroute sectors (Toledo and Domingo sectors) were the selected for the validation scenarios. For more details on the training process of the XAI algorithms please refer to the D4.1 TAPAS Integrated Prototype deliverable [14].

- The XAI component is integrated with the validation platform, and it is able to receive and consume information from the ATC / FDPS environment.
- As the SACTA system will not be able to consume, and automatically implement, solutions that are being proposed by the XAI automation, a 'ghost' controller position will be used to emulate the 'automated' implementation of those actions
- Available actions will be limited to a set of mitigation solutions including, but not necessarily limited to:
    - Lateral manoeuvres to solve conflicts
    - Speed-control manoeuvres to solve conflicts
    - Direct-to manoeuvres to solve conflicts
    - Level-change manoeuvres to solve conflicts
- Existing conflict alert (e.g. STCA) and conformance monitoring functions that are available on the SACTA system/simulator will be disabled in favour of using those provided by the XAI components
- Scenarios will run in synchronised real-time with regular flight plan and track (position) updates being shared with the XAI on an agreed frequency (e.g. every 30-seconds) – to be agreed between the XAI developer and the SACTA/RTS technical team.
- If solutions are unable to be provided in sufficient time to solve any conflict, or the human operator is unable to rationalise and understand a proposal in order to implement it before the start of the problem, the solution will not be applied (levels 2 only) – note if this situation occurs this will be a strong indicator that the proposed approach has some on-time performance and/or safety related issues.
- The available CWP used in the simulator platform provides the human operator with all the same features that are available in the real operational environment.
- A co-located visual analytics and explanation display is included along-side the controller working position.
- VA components can consume data from both the XAI automation component and the ATC simulator (through a connexion with the XAI component, which will connected at the same time with the ATC platform) to provide suitable visual and information and scenario drill down functionality (if sufficient time is available to allow it to be consulted)

5.3 ATC-CD&R Validation Infrastructure

The experiments will be carried out using the ENAIRE/CRIDA Real-Time-Simulation platform that is based on the operational SACTA tool which is used in all the Spanish operated ACCs.

The CWP will be the same one that is used in daily operations and will be manned with one Executive (Radar) ATC operator. Additional feeder sectors and/or the 'ghost' ATC position that will be used to emulate the 'automated' execution of proposed actions (level 3) or implementation of actions when the ATC operator accepts them (level 2) will also be include on the simulation platform.

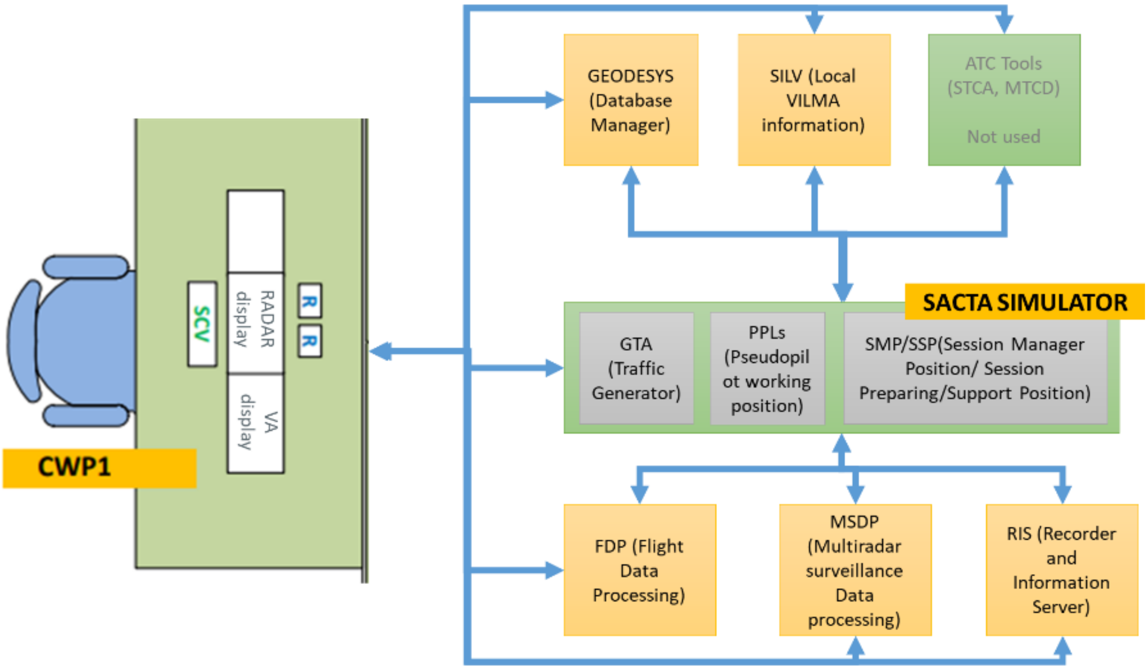


Figure 4. Diagram on SACTA platform and available sub-systems during the CD&R exercise validation.

The XAI and VA explanatory support components will also be (loosely) integrated with the SACTA platform and the CWP will have a co-located VA display to help in the provision of solutions and explanatory information. Some (limited) drill down features will also be available, and these may be consulted if the time between the identification of the problem and the latest time that a solution needs to be implemented permits.

Using the SACTA CWP, controllers will be able to perform all the usual functions that would be carried out on a daily basis when working a sector in the Spanish airspace. However, the conflict alert (SACTA conflict detection tool STCA) and conformance monitoring features will be disabled – and the equivalent XAI tool features will be used instead.

Flight plan (current and updated) and radar track (4D position) data will be shared with the XAI at a pre-agreed frequency (e.g. every 30 seconds) to allow the automation tools to maintain a clear vision of the current and planned traffic states.

Conflict situations and recommended actions will be shared by the XAI and depending on the level of automation those actions will be implemented (by an operator working a 'ghost' position) either when authorised (by the ATC operator controlling the measured sector(s) – Level 2) or automatically (when the XAI makes the proposal for a resolution action – Level 3).

All other features of the SACTA CWP will be made available to the ATC controllers performing the validation exercise scenarios. However, it should be remembered that this is a simulation environment not an operational one, therefore there are certain limitations on the used SACTA sub-systems, but this should not suppose a major impact on the exercise since the main functionalities (see previous figure) will be available to the ATCO.

5.4 ATC-CD&R Validation Levels of Automation

The CD&R validation activities will assess three different levels of automation level 1, level 2 and level 3.

5.4.1 Automation Level 1

For automation level 1, the ATCO will be the one responsible of proposing and implementing resolution actions when a conflict arises. Similarly to the current operations methods they will have the aid of the XAI tool only for conflict detection.

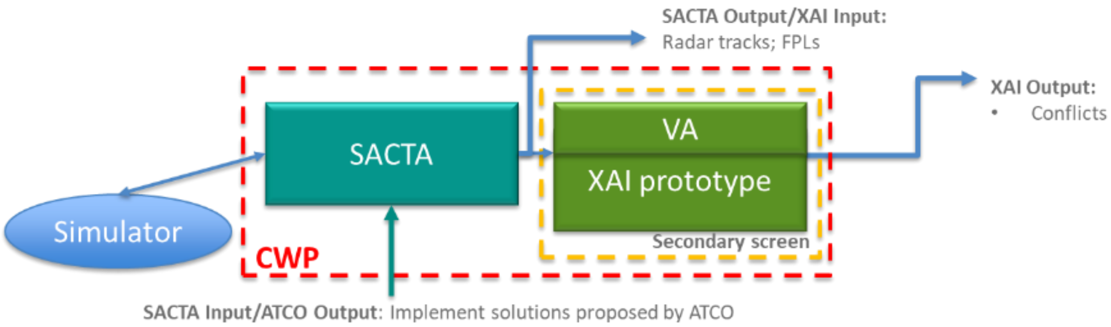


Figure 5. CD&R validation approach diagram for automation level 1.

Therefore, during the real time simulations the XAI prototype will consume real data (radar tracks and flight plans) from the simulation platform to minimise possible inconsistencies between both systems and to propose accurate detections and alerts of new conflicts to the executive controller.

5.4.2 Automation Level 2

For automation level 2, the ATCO will be the one responsible for implementing the resolution actions, proposed or not by the XAI prototype. This may be achieved either 1) by the ATC operator themselves – where the operator will implement the proposed solution using the available SACTA tools, or 2) by the ATC operator confirming that a recommended action should be applied (and the 'ghost' operator implements the action using the available SACTA tools).

During the real time simulations, the XAI prototype will consume real data (radar tracks and flight plans) from the simulation platform to minimise possible inconsistencies between both systems.

The XAI prototype will provide through a secondary screen the information about possible conflicts and the conflict resolutions proposed. Sharing the same screen as for the XAI prototype output, different Visual Analytics components will be displayed to help to explain the situation and possible solutions to the ATCO. The figure below summarises the CD&R validation approach for automation level 2.

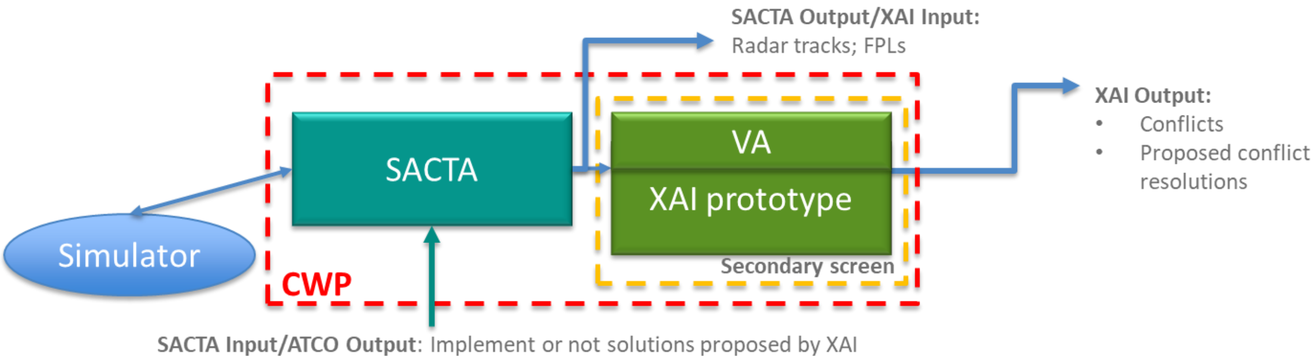


Figure 6. CD&R validation approach diagram for automation level 2.

5.4.3 Automation Level 3

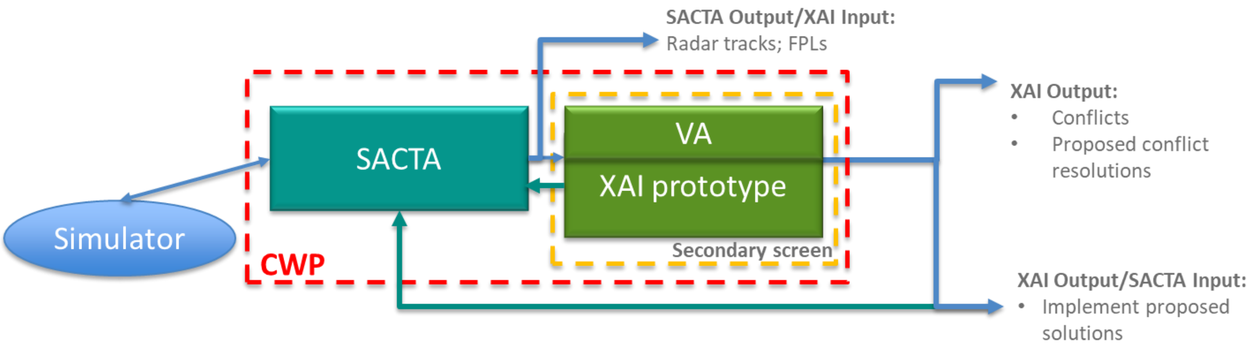


Figure 7. CD&R validation approach diagram for automation level 3.

For automation level 3, the proposed resolution actions should be implemented automatically without any ATCo intervention. The workflow is very similar to the one presented for the automation level 2, but the main difference is that the ATCO does not choose to implement the prototype proposed solutions, they are implemented in any case.

In practice, as it may be somewhat difficult to incorporate *fully automated* CD&R solutions the target platform (SACTA), a second 'ghost' working position is provided through which non-measured ATCOs or support team members are able to feed the system with those actions, without coordinating those actions with the measured ATCOs – thus emulating the automated execution but with no need to adapt the working platforms.

5.5 ATC-CD&R Validation Scenario(s)

The scenarios will include a reference scenario, along with different solution scenarios in which several pre-existing separation issues have been included. However, as with all Real-Time experiments of this kind, other issues may manifest as actions are performed in the scenario which could in turn generate new conflict situations.

In this case, the term reference scenario refers to a scenario at automation level 1.

This level is considered to encompass the current operational methods in most countries and ACCs. For example, in Spanish ATC services provision, automation is included but it is currently limited to being an aid for detecting conflicts. The proposal or automatic resolution of those conflicts is not available. Other regions may have more, or less automation depending on the technology that is available to them. Solution scenarios correspond to those runs tested with automation level 2 or automation level 3 during the execution of the validation exercises.

The validation scenarios will be based on Madrid ACC enroute upper sectors Domingo Upper (DGU) and Toledo Upper (TLU), which are adjacent sectors managing traffic from FL345 to UNL.

The traffic samples will use historical traffic samples from different days in June and July 2019 (the 25th and 30th of June and the 4th of July 2019). From these days, several hours of traffic will be extracted, modified accordingly to create enough conflict situations, and then will be introduced into the SACTA platform and traffic simulator.

It is planned that each scenario will last for a maximum of 30-minutes, however times may vary depending on the use-case for each of the specific scenarios.

Due to time and resources limitations, ATC operational users supporting executive positions will be assigned responsibility for one of the two upper airspace sectors located in the Madrid ACC. (Note the use of Madrid sectors and traffic is to avoid that the same data is used for the validation exercises as the data which was used to train the XAI – which was based on 1-year of data for the Barcelona ACC).

The concept will be tested over three days, between the 7th to the 9th of March. The first day will be focused on training, whilst the other two days will focus on performing several runs at different automation levels. It is also foreseen to test failure scenarios of the XAI system during the execution of level 3 exercises, where the ATCO should try to recover control (runs identified with **).

	MONDAY 07/03/2022	TUESDAY 08/03/2022	WEDNESDAY 09/03/2022
	Training *1. Know Exercise Objective and get familiar with TAPAS operational concept* *2. Train on supporting tools for CDR&R*	Execution *1. Assess effect on human performance of XAI and VA automation DSTs*	Execution *1. Assess effect on human performance of XAI and VA automation DSTs*
9:00 - 9:30	Welcome and introduction	Introduction of today's executions	Introduction of today's executions
9:30 - 10:00	Introduction to TAPAS project and CD&R exercise	SCN - TS4 – DGU - Level 1	SCN - TS4 – DGU - Level 1
		Questionnaires	Questionnaires
10:00 - 10:30		SCN - TS1.2 – TLU - Level 2	SCN - TS1.2 – TLU - Level 2
10:30 - 11:00	Introduction and training on TAPAS CD&R tool		
11:00 - 11:30		Questionnaires	Questionnaires
		COFFEE BREAK	*COFFEE BREAK*
11:30 – 12:00	*COFFEE BREAK*	SCN – TS2.1 -DGU - Level 3**	SCN - TS3 - DGU - Level 3**
12:00 - 12:30	SCN - TS1.1 –TLU - Level 1		
12:30 – 13:00	Questionnaires	Questionnaires	Questionnaires
	COFFEE BREAK	*COFFEE BREAK*	*COFFEE BREAK*
13:00 – 13:30	SCN - TS 2.1 – DGU - Level 2	SCN - TS3 - DGU - Level 2	SCN – TS2.1 -TLU - Level 2
13:30 – 14:00	Questionnaires	Questionnaires	Questionnaires
14:00 - 14:30	Wrap-up	Wrap-up	Wrap-up

Table 6. Planned agenda for CD&R exercise execution.

The planned agenda for the CD&R exercise execution is presented above. Please refer to sections 5.5.1 and 5.5.2 for a more detailed description on the airspace and traffic used, as well as for the explanation of the code used to name the runs.

5.5.1 ATC-CD&R Analysis Region

Validation scenarios will be based on the provision of Airspace Navigation Services in one of two upper airspace sectors (currently Toledo and Domingo upper sectors – as shown in the images below).

Although these are enroute upper airspace sectors, from FL345 to UNL, they include both flights that are in their cruise phase as well as flights in evolution that are in their climbing or descending phase to nearby airports such as Madrid Barajas airport. Therefore, they offer an adequate traffic mix of both evolution and cruise flights to be tested.

Due to human resources constraints and limitations regarding the XAI prototype, which is trained to focus on a single sector at each time, each run will only focus on one of these two sectors during each test run.

Figure 8. ATC-CD&R Simulated region – Toledo Upper Sector.

Figure 9. ATC-CD&R Simulated region – Domingo Upper Sector.

Additional feed sectors (upstream and/or downstream) will also be included in the simulation but will not be actively managed (or may be supported by members of the analysis team to provide coordination services for the measured sectors if required).

5.5.2 ATC-CD&R Analysis Traffic

To run the exercises, it will be necessary to have a traffic sample of flight plans that would be simulated using the ATC-platform. The traffic sample used will be an actual traffic sample and will not be part of the training set used to develop the XAI prototype.

Traffic samples that are representative of current day operations in the measured sectors will be created for each of the (30-min) scenarios and will include all overflying traffic (in cruise) for the major flows/routes in the target airspace, as well as a mix of traffic in evolution (e.g. climbing into the main flows from regional airports or descending towards those airports).

Traffic will be selected from busy summer days in the June-July 2019 period to ensure that a) a high level of demand is included in the traffic used and b) that due to high traffic levels, conflict resolutions will need to consider other surrounding traffic as part of the solutions. Additionally, the final traffic samples to be used during the validation exercises will be verified beforehand to guarantee they present a sufficient number of conflicts of interest for the XAI prototype.

The resulting traffic samples will vary in terms of traffic demand levels and number of conflicts. This will allow the team to test different scenarios ranging from low to high complexity. To achieve this, four different traffic samples will be used, named as TS1, TS2, TS3 and TS4, where the number on the traffic sample naming relates to the relative complexity of the sample and will be prepared as follows:

- TS1 traffic samples present low complexity, low traffic demand (average OCC of less than 5 flights in windows of 5 minutes) and a low number of conflicts (2 conflicts per 15 minutes). For these traffic samples night hours will be selected from 2:00 to 3:00 from the 30th of June.

- TS2 traffic samples present medium-low complexity, medium traffic demand (average OCC of more than 5 flights and less than 10 flights in windows of 5 minutes) and a low number of conflicts (3 conflicts per 15 minutes). For these traffic samples morning hours will be selected from 8:00 to 8:30 from the 4th of July.

- TS3 traffic samples present medium complexity, medium traffic demand (average OCC of more than 5 flights and less than 10 flights in windows of 5 minutes) and a medium number of conflicts (4 conflicts per 15 minutes). For these traffic samples morning hours will be selected from 8:00 to 8:30 from the 25th of June.

- TS4 traffic samples present very high complexity, medium traffic demand (average OCC of more than 5 flights and less than 10 flights in windows of 5 minutes) and a medium number of conflicts (6 conflicts per 15 minutes). For these traffic samples morning hours will be selected from 8:00 to 8:30 from the 25th of June.

Please note that since the validation technique chosen is RTS, unexpected events can occur that lead to different conflict situations and number of conflicts than those planned.

Additionally, another traffic sample will be prepared to be used during the initial runs for training purposes. This sample will consist of traffic from the 25th of June, from 8:30 to 9:00, and will be similar to the TS2 samples in terms of conflicts and traffic demand.

5.6 ATC-CD&R Analysis Validation Exercises

The CD&R experiments will involve operational staff from ENAIRE and PANSA - licensed Air Traffic Controllers that will act as executive controllers and whose feedback will be used as input for further analysis to elaborate the basic principles for transparency.

To extract ATCOs input, TAPAS project plans to use questionnaires and other techniques (video and audio recording of the controller working positions, over the shoulder observations, debrief sessions etc.) with which to collect the experts' opinion. Surveys performed 'after' the experiment will be used as a preference, along with questionnaires that will be designed by TAPAS validation team. The questionnaires will include multichoice or 'score-based' questions combined with open-ended responses that can be analysed independently at a later time. Other aspects of the questionnaires are yet to be determined.

Additionally, for further analysis, output data will be recorded from the ATC-platform, such as radar track, flight plans, control actions and the audio and video of CWP radar screen. These data recordings will be used to support the generation of performance analysis metrics including flight efficiency, safety, performance, and on-time notification of issues/application of proposed actions.

The expected results obtained through TAPAS CD&R validation exercises could be reproduced elsewhere. However, in order to duplicate them, it must be taken into account that the particular use of the SACTA ATC-Platform, whose simulator determines how the flights are flown, as well as the methods and techniques used by the XAI prototype may make this a challenging task.

Three types of scenario will be produced to support the validation analysis. For each of the scenario types, several exercises will be performed, depending on the availability of operational experts and the ability to create the associated simulation environment and traffic data to support the experiments. The three scenario '*types*' are described below:

5.6.1 CD&R Scenario #1 – Level 1 Automation

5.6.1.1 Description & Scope

The initial scenario will be executed with DST support functions operating at automation level 1.

At this level, only the Conflict Detection functions are performed by the machine. All other functions are performed by the human operator based on the information that is provided from the DST and any information that is available from the collocated VA tools.

The scenario will be primarily used to obtain baseline metrics with the XAI components being used to provide alerts on future conflicts. This will help to determine that the alerting function is able to identify conflicting situations with a suitable amount of time available to allow the operator(s) to determine a mitigation action that can solve the issue in a safe, efficient, and timely manner.

All scenarios will be executed in synchronised real-time and if alerts are provided too late to allow the operator to respond, these will be recorded as unsafe operations (from the automation) and will require some level of mitigation action (if that is possible in the available time).

The scenario will also help to familiarise the user with the various features of the prototype VA and explanatory support information components.

At level 1, a limited set of Visual Analytic features will be available to support the analysis of the traffic scenarios, and interactive exploration of sector and demand scenarios. These will mainly be used to a) help the operator become familiar with the VA/explanatory features that are available and b) help to determine whether the information is being provided in a clear, understandable, and timely fashion.

Conflicts identified by the XAI tool will be signalled to the ATCO users using either the CWP client interface or through features provided by the VA components.

Assuming the analysis of the conflicts that are detected are able to be performed in the allotted time, the ATC operator can prepare suitable conflict resolution actions using the existing SACTA CWP client interface and implement them to evaluate the suitability of the solutions that they have been able to develop.

5.6.1.2 Expectations

It is expected that all the conflicts that are identified by the XAI are also able to be identified by the ATCO in the simulated ATC environment and that the information provided allows them to both determine a suitable mitigation action and implement it in a suitable time before the conflict occurs. Once implemented, both the ATC operator and the XAI component should be able to monitor the affected flights to ensure that they conform to the proposed action(s).

It is also expected that all the separation issues that may occur in each of the scenarios are a) detected and reported by the XAI analysis component and b) are published at an appropriate time offset with sufficient additional explanatory information to allow the ATCO to develop and implement an appropriate solution.

The human operator can consult the Radar Display and the VA support components to understand where and when the potential conflict identified by the XAI is expected to occur. This will help then to identify affected flights and other relevant characteristics, such as the minimal distance between the conflicting trajectories, as well as to obtain additional explanatory information to help solve those issues. However, at level 1, where no resolution proposal is provided by the XAI, it should be noted that the detection of potential conflicts will be done using the XAI prototype and therefore, using AI/ML techniques and it is possible that type of tool may detect false positives, as is also the case for other types of conflict alerting tools. This is the reason why it is important to allow users to investigate alert situations quickly using the VA and ATC platform to determine why the XAI sees a situation as being in conflict.

5.6.1.3 Objectives

The objective of the automation level 1 is twofold. Firstly, the aim is to validate the set of conflicts identified by the XAI tools for the scenario and secondly it is to allow the operational user to further investigate them using the associated VA components.

5.6.1.4 Scenarios

Suitable data from the ENAIRE archives will be selected to create the validation scenarios. As previously mentioned, actual traffic samples from June-July 2019 (slots of 1 hour) will be used. Within these traffic samples the trajectories of the flights crossing the entire Spanish airspace will be included (although only one or two sectors will be of interest at the same time due to technical and operational staff limitations). In particular, the planned trajectory will be the one used and loaded into the SACTA platform and considered by its internal traffic simulator.

Once the traffic samples are loaded into the ATC platform, the XAI component will have immediate access to them by consuming the required files (radar track and flight plans - including information on crossed waypoints and sectors). These will be available according to the agreed frequency (e.g.: every 30 seconds).

Results from the XAI analysis will be provided to the VA component to support the alert to the ATCO of possible conflicts (no solutions are provided to the user at automation level 1). Additionally, VA components related to the exploration of these detections will be available for the user.

The users will be located in the existing SACTA CWP with access to its radar display thereby allowing them to monitor the flights under their responsibility (e.g. consult their flight plan and current radar track) and to implement any resolution actions they decide upon. As indicated previously, the chosen sectors will be upper sectors from Madrid ACC (Toledo Upper (LECMTLU) and Domingo Upper (LECMDGU)). These sectors were not included in the training data (only Barcelona data was provided) to ensure the XAI algorithm is not overfitted. Nevertheless, some tests will be performed prior to the exercise execution using these new Madrid ACC sectors, to ensure that the XAI algorithm presents an acceptable performance with those and so that the validation exercises can be executed.

5.6.1.5 Assumptions and Limitations

As the XAI and SACTA tools include their own trajectory and conflict identification features that operate independently, to avoid differences between the two systems, the conflict alert features in SACTA will be disabled. Nonetheless, it is assumed that the conformance for key indicators such as the number, location, start, end type etc, of each conflict should have a close correlation and that all conflicts are correctly identified by the XAI in a timely fashion. This will be further analysed in post operational analysis to determine performance indicators such as time to conflict and to verify that no separation issues have been missed by the automation tools.

As scenario #1 remains at a very low level of automation, most of the more advanced VA features will not be used in support of this scenario, and comparisons will be performed by the operational user via the SACTA CWP client interfaces.

5.6.2 CD&R Scenario #2 – Level 2 Automation

5.6.2.1 Description & Scope

Scenario #2 will focus on use of the XAI decision support tools at Level 2 automation.

At this level, many of the tasks are performed automatically by the XAI support tools and the user is able to consult the VA display components to navigate through problems that have been identified and solutions that are being proposed.

In scenario #2 the XAI will provide full analysis of proposed ATC flight plans to allow it to identify potential conflict situations and their characteristics. Having identified conflicts, the XAI will also try to determine suitable resolutions actions, but these are only provided as proposed mitigation actions, probably via the VA/explanatory display components. The human is still involved in the acceptance/rejection of the proposed solutions and should implement them (if accepted) within the simulation environment (SACTA).

The process of implementing a solution proposed by the automation may either be done by simply accepting the proposal (and the 'ghost' controller will implement it once the acceptance is performed) or by implementing the recommended action themselves.

In both cases, the remaining time between the detection of the conflict, the provision of a mitigation action proposal and the implementation of that action is extremely important, since if these steps are not taken at a suitable time offset before the start of the identified issue, the solution may not be sufficient to solve the issue, or may even not be able to be implemented (e.g. if it is provided too late).

It is not currently expected that the XAI will provide a set of (prioritised) resolutions to allow the operational user to select from the available choices – rather it is anticipated that only a single solution will be proposed, which the user can with accept/implement or reject (and find their own solution). All proposals made by the XAI should have sufficient information provided in the VA components to allow the users to rapidly understand the problem and the proposed solution. If time permits, solutions can be investigated further to help ensure transparency using the VA components and additional drill down information can be accessed via the conflict/resolution explorer – but this may not be possible if the time to conflict is too short.

Proposals that are considered as suitable solutions to the detected issues are either created by the human and implemented in the simulator environment or may simply be 'accepted' and the 'ghost' controller will implement them.

Conformance monitoring of the execution and impact of the solutions is supported through the XAI component. However, the human operator will also be able to monitor the compliance via the CWP traffic display.

5.6.2.2 Expectations

At automation level 2 it is anticipated that the majority of the decision-making process is being performed by the XAI DST. The operational user, having gained confidence in the conflict detection process during scenario #1, is able to confirm that those conflicts are realistic, and resolutions being proposed (supported by the explanatory displays) are able to be reviewed using experience, the CWP display, and additional information provided via the explanation support tools.

The human will have access to the full set of VA support tools to allow them to investigate the solution and to understand why the XAI has proposed these actions, including the ability to identify the impacted flight and how the proposed action will be implemented and why. The human will also have access to additional graphical support tools that illustrate the steps in the process by which solutions have been reached and the overall impacts of different solutions – provided that sufficient time is available to allow it.

Using the information available in the CWP display and the VA support components, the human can make informed judgements on the most appropriate resolution actions to respond to the identified conflict.

Having made the decision, the human may still be involved in the creation of the corresponding resolution action which will be implemented in the simulated ATC environment through the functions provided in the CWP interface. Alternatively, a simple action to 'accept' the proposed manoeuvre could be supported in which case the corresponding action will be implemented 'automatically' by a 'ghost' controller.

Impacts of the implemented measures, and any remaining/new conflicts can be monitored either interactively using the CWP working position, using the proposed XAI conformance monitoring tools or as a post processing activity.

5.6.2.3 Objectives

The objective of scenario #2 is to allow the XAI components to both identify conflict situations and automatically provide (sets of) solutions that can be used to help resolve those issues.

At automation level 2, the human is still involved in the review and selection of the actions that should be implemented, and to ensure that this can be done with a good knowledge of what is happening in the scenario, and how solutions have been identified, advanced VA components are provided.

The main objective is to evaluate how these VA components can provide key information to the operator in a timely manner. It is also designed to help determine whether that information can foster a good understanding of what is being proposed, and if the user can maintain a sufficient picture of what the solutions offer, and why.

Additionally, the user should be capable of distinguishing between different potential solutions, and with the help of the VA features, to select the most appropriate ones for implementation (in the case that multiple solutions are offered), or to allow them to reject a given proposal and select their own solution.

5.6.2.4 Scenarios

Similar to the previous scenario, data from the ENAIRE archives will be selected to create the validation scenarios. Actual traffic samples from June-July 2019 (slots of 1 hour) will be used. Within these traffic samples only the trajectory of the flights crossing the entire Spanish airspace will be included (although only one or two sectors will be of interest at the same time due to technical and operational staff limitations). In particular, the planned trajectory will be the one used and loaded into the SACTA platform and considered by its traffic simulator.

Once the traffic samples are loaded into the ATC platform, the XAI component will have immediate access to them by consuming the required files (radar track and flight plans including information on crossed WP and sectors) according to the established frequency (e.g.: 30 seconds).

Results from the XAI analysis will be provided to the VA component to support the alert to the ATCO of possible conflicts and proposal of possible solutions. XAI component will also include the conformance monitoring functionality to determine whether the trajectories are following the proposed solutions or not. Additionally, VA components related to the exploration of these results will be available for the user.

The users will be working within the CWP with access to its radar display that will allow them to monitor the flights under their responsibility (consult their flight plan and current radar track) and implement the resolution actions proposed or not by the XAI component. The measured sectors will be upper sectors from Madrid ACC (Toledo Upper (LECMTLU) and Domingo Upper (LECMDGU)). These sectors are not included in the training data (only Barcelona data was provided) to ensure the XAI algorithm is not overfitted.

5.6.2.5 Assumptions and Limitations

Scenario #2 assumes that the human has developed a sufficient level of confidence in the XAI support tool to allow conflict situations to be automatically identified by the system, and to allow the XAI components to propose potential solutions for the human to assess them and decide to implement them or not.

It is also assumed that, when needed, the human operator can explore the proposed solutions using the corresponding VA functionality in a timely fashion to obtain a clear understanding of problem and to make comparisons between different proposals (if available) and to track the steps that were carried out to arrive at the various solutions being proposed.

The user should also be able to follow how the development of any given solution has identified and modified flight plans as it works towards the objective of solving the known issues. However, in doing such a task, the user should not have to spend extensive amounts of time to obtain the required information.

5.6.3 ATFCM Scenario #3 – Level 3 Automation

5.6.3.1 Description & Scope

Scenario #3 will execute the same processes as those used in scenario #2 with the exception that when feasible, the most appropriate solutions will be automatically applied and implemented in the CWP interface.

The human is still involved in the process but takes on a monitoring role, potentially being required to ‘confirm’ that the proposed action is implemented, to maintain awareness that these actions are being taken by the system, but not being given an option to modify or refuse them.

In this scenario the focus is heavily on how the VA support tools can be used by the human to help to understand what problems are being solved, which solutions have been identified and why.

Particular importance should be given to the evaluation of the situational awareness of the human, to ensure that they remain fully aware of what is happening during the process and conformance monitoring to ensure that the actions that were proposed are being correctly implemented by the traffic concerned.

5.6.3.2 Expectations

While monitoring the situation, the human should be capable of understanding which problems are being considered and why.

The human operator should also be fully aware of the solutions that have been identified and when they are implemented, but no specific action is required on their part.

The human is able to respond to the evolving situation and consult the VA components to investigate how theCD&R scenario is evolving without intervening in the on-going process.

If asked, the human is able to identify the problems that are being solved and to describe the solutions that are being developed and why they are appropriate in resolving the situation.

5.6.3.3 Objectives

The objective of scenario #3 is to provide the XAI components with full freedom to identify conflicts and automatically determine and implement suitable responses from the sets of solutions that could be used to help resolve those issues in a timely manner.

The human is only involved in a monitoring role, and to ensure that they remain aware of what is happening in the scenario, and how solutions have been identified, advanced VA components are provided.

The main objective is to evaluate how these VA components can provide key information to the operator to ensure a good understanding of what has been proposed and implemented.

The user must be able to maintain a sufficient picture of what issues have been addressed, how they have been solved and why.

Additionally, the user should be capable of reviewing alternative potential solutions, and with the help of the VA features, to help to assess whether the solutions that were actually implemented were the most appropriate.

Users are also able to analyse the impact of the implemented solutions to ensure that the issues have been solved, and to act upon any remaining problems that require their action.

5.6.3.4 Scenarios

Similar to the previous scenarios, data from the ENAIRE archives will be selected to create the validation scenarios. Actual traffic samples from June-July 2019 (slots of 1 hour) will be used. Within these traffic samples only the trajectory of the flights crossing the entire Spanish airspace will be included (although only one or two sectors will be of interest at the same time due to technical and operational staff limitations). In particular, the planned trajectory will be the one used and loaded into the SACTA platform and considered by its traffic simulator.

Once the traffic samples are loaded into the ATC platform, the XAI component will have immediate access to them by consuming the required files (radar track and flight plans including information on crossed WP and sectors) according to the established frequency (e.g.: 30 seconds).

Results from the XAI analysis will be provided to the VA component to support the ATCO in maintaining his situational awareness regarding the detected conflicts and implemented solutions. XAI component will also include the conformance monitoring functionality to detect whether or not the trajectories are following the proposed solutions. Additionally, VA components related to the exploration of these results will be available for the user.

The users will be working in the CWP with access to its radar display that will allow them to monitor the flights under their responsibility (consult their flight plan and current radar track) and monitor the implemented actions by the XAI component. In this case the actions are implemented by a 'ghost' air traffic controller that will also be using a CWP focused in the same sector and the VA display with the actions to be implement proposed by the XAI.

The used sectors will be upper sectors from Madrid ACC, Toledo Upper (LECMTLU) and Domingo Upper (LECMDGU). These sectors are not included in the training data (only Barcelona data was provided) to ensure the XAI algorithm is not overfitted.

5.6.3.5 Assumptions and Limitations

Scenario #3 lets the XAI support tools identify conflicts, automatically notify them, and to identify and select potential solutions. The system also implements these actions automatically.

It is assumed that the system can indicate to the human operator that is acting in a monitoring role when the different operations have occurred. Nevertheless, additional visual cues (e.g., a need to confirm that a solution can be implemented) may be included to help maintain awareness of what is being implemented and when.

It is also assumed that the human operator can explore the proposed solutions at any time during the process using the corresponding VA functionality it sufficient time exists to allow that.

This should help them to maintain a good overview of problem scenarios, to make comparisons between different proposals and to track the steps that have been performed leading up to and executing the proposed solutions.

The user should also be able to follow how the development of any given solution has identified and modified flight plans as it works towards the objective of solving the known issues.

Additionally, the user should also be able to use the VA support to identify situations where solutions result in a knock-on effect, e.g., creating new conflicts in different parts of the sector as a result of a proposed action.

It is also assumed that the human can consult the conflicts that have been automatically identified by the DST and to understand how the proposed solutions intend to resolve those issues and why.

In the event of any remaining issues or system failure / corruption, it is assumed that the human will be able to resolve these manually to complete the process using the available features in the SACTA CWP working position.

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