TAPAS – Unravelling the AI/ML "black box" in ATM

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ENGAGE TC2 – AI, ML and Automation Workshop

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CRIDA I+D+i - ATM

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indra

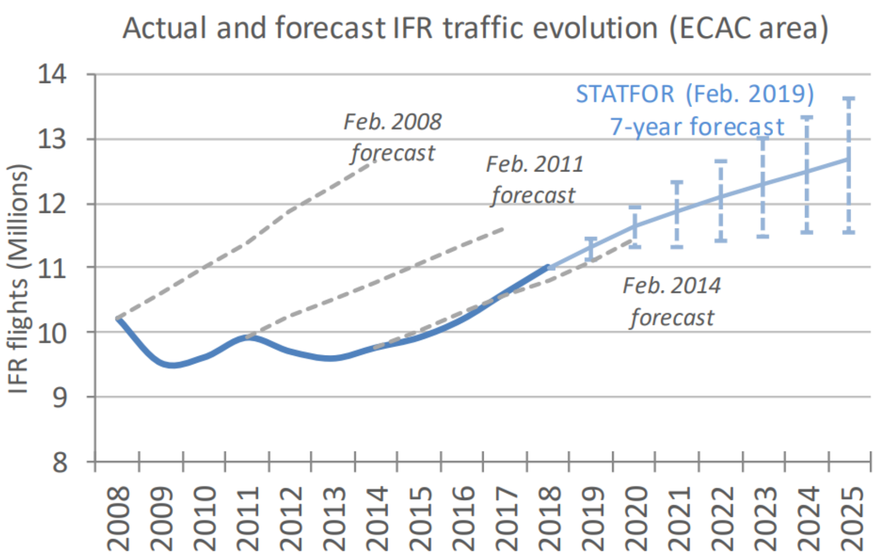
ISA Innovation for Sustainable Aviation

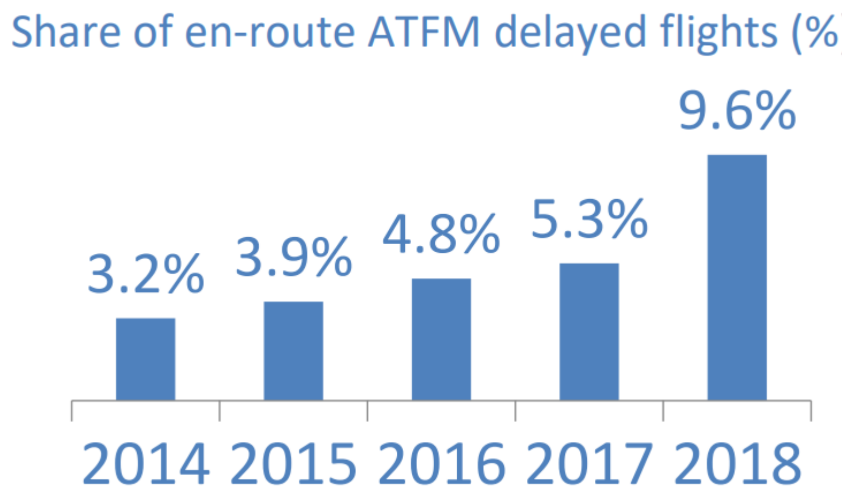
UNIVERSITY OF PIRAEUS RESEARCH CENTER

Previous collaboration in successful projects (DART, datAcron, …)

What is TAPAS about?

Current ATM system very close to (or already at) saturation point





Pre-COVID (which is not expected to have an impact more than 2-3 years in traffic)

Most priority need: Capacity -> Higher levels of Automation, as key enabler

What is TAPAS about?

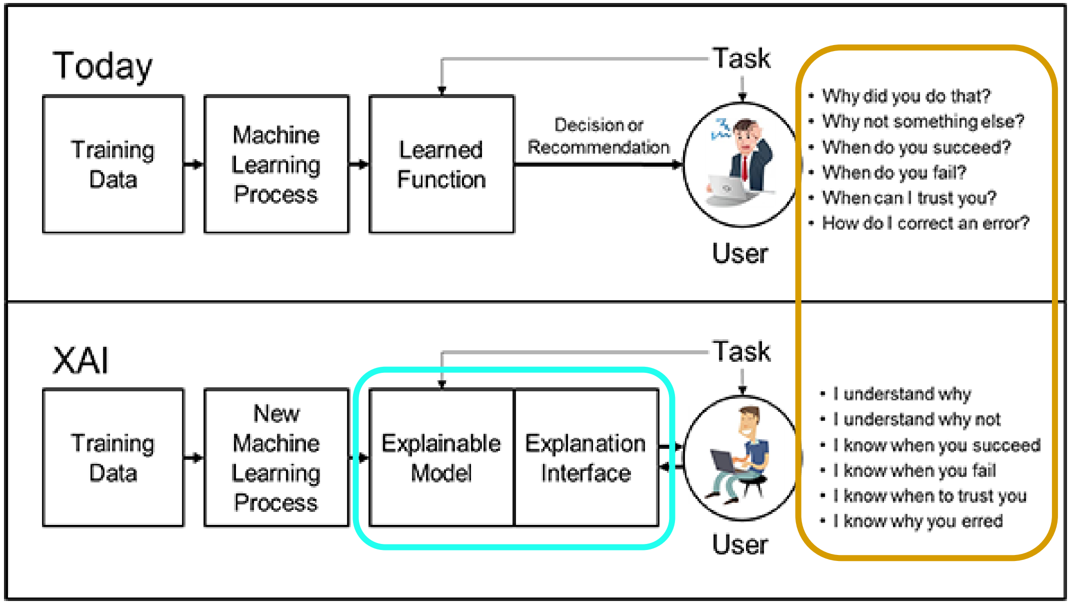
Introduction of AI/ML techniques as a mean to achieve higher levels of automation

But… this brings new challenges: ATM is a safety-critical domain, where operators **need to rely in the system**, which in previous experiences is not trivial

TAPAS: *Towards an Automated and exPlainable ATM System*

Focus on **transparency of AI/ML models** applied in ATM use cases (highest priority to enable adoption of these technologies)

Topic **SESAR-ER4-1-2019**, **"Digitalisation and Automation Principles for ATM"**



This is conceptually TAPAS' goal, oriented to not just a particular case but trying to provide a framework of principles

Transparency

In TAPAS context, Explainability=Transparency

In AI decisions is about getting **high levels of confidence** regarding the veracity of a decision or answer provided by a machine for a given problem

Not all use cases will require a similar level of explainability: it will depend on several factors, such as safety criticality.

Example: Neural networks tend to provide valuable results, but they are a black-box. When and how they could be applied?

TAPAS will address **two use cases**: Non-Safety critical (ATFM, taking over DART system) and Safety critical (CD&R, ATC related)

Automation in ATM

Today (Baseline)

TAPAS target

		Definition of Level of Automation per Task					Automation Level Targets per MP phase (A, B-C, D)	
	Definition	Information Acquisition and Exchange	Information Analysis	Decision and Action Selection	Action Implementation	Autonomy	Air Traffic Control	U-space services
Actions can only be initiated by Human	**Level 0** *Low Automation* — Automation supports the human operator in information acquisition and exchange and information analysis							
	Level 1 *Decision Support* — Automation supports the human operator in information acquisition and exchange, information analysis and action selection for some tasks/functions							
	Level 2 *Task Execution Support* — Automation supports the human operator in information acquisition and exchange, information analysis, action selection and action implementation for some tasks/functions. Actions are always initiated by Human Operator. Adaptable/adaptive automation concepts support optimal socio-technical system performance.							
Action can be initiated by Automation	**Level 3** *Conditional Automation* — Automation supports the human operator in information acquisition and exchange, information analysis, action selection and action implementation for most tasks/functions. Automation can initiate actions for some tasks. Adaptable/adaptive automation concepts support optimal socio-technical system performance.							
	Level 4 *High Automation* — Automation supports the human operator in information acquisition and exchange, information analysis, action selection and action implementation for all tasks/functions. Automation can initiate action for most tasks. Adaptable/adaptive automation concepts support optimal socio-technical system performance.							
	Level 5 *Full Automation* — Automation performs all tasks/functions in all conditions. There is no human operator.							

Degree of automation support for each type of task

Use cases

Example (ATFCM)

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 • Capacity Measures (sector configuration) • ATFCM Scenarios • Trajectory Measures • ATFCM Regulation • Selection of candidate flights • Analysis of the DCB measure impact – What-if	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

General Project Objectives

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

The project will explore the use of XAI and VA to apply them in the operational cases considered, through practical experiments and validation activities in simulation platforms.

General principles

Selection and development of suitable and explainable AI/ML methods in the operational cases identified, to fit the needs of transparency as expressed in the explainability criteria developed for each automation level and according to actors' needs

Specific examples and prototypes supporting the general principles

Exploration of additional opportunities:

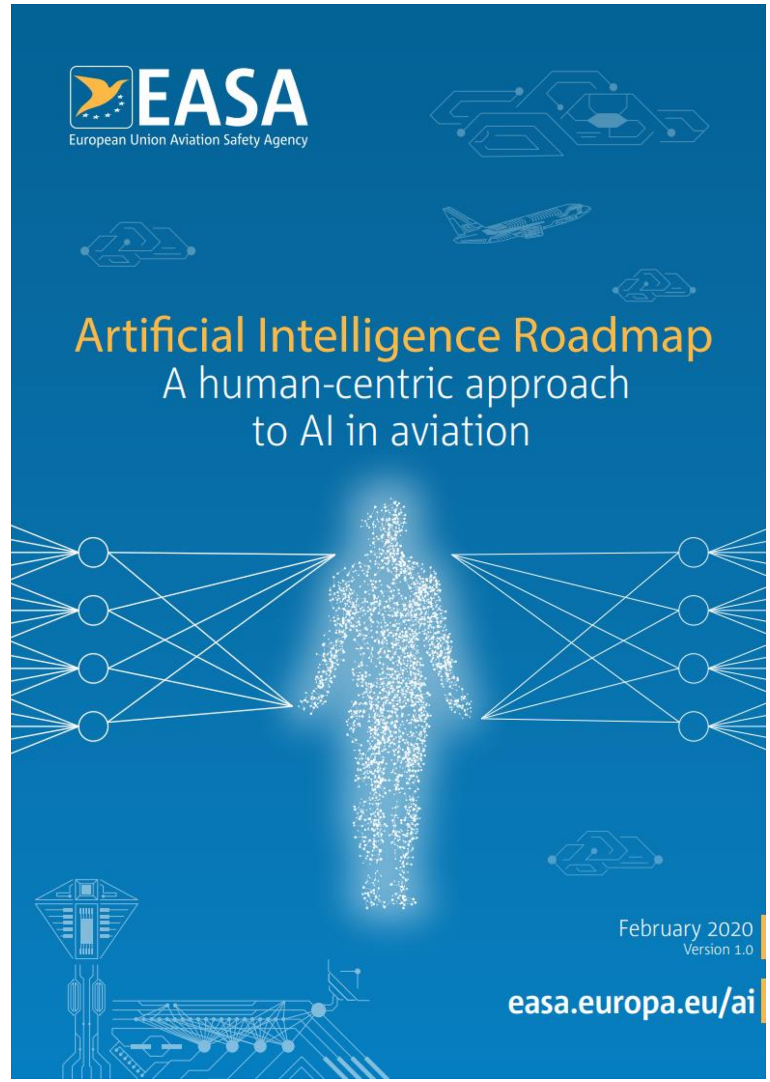
- *Generalisation*
- *Feedback on MP Automation Levels definition*
- *…*

WiP: Levels of Explainability

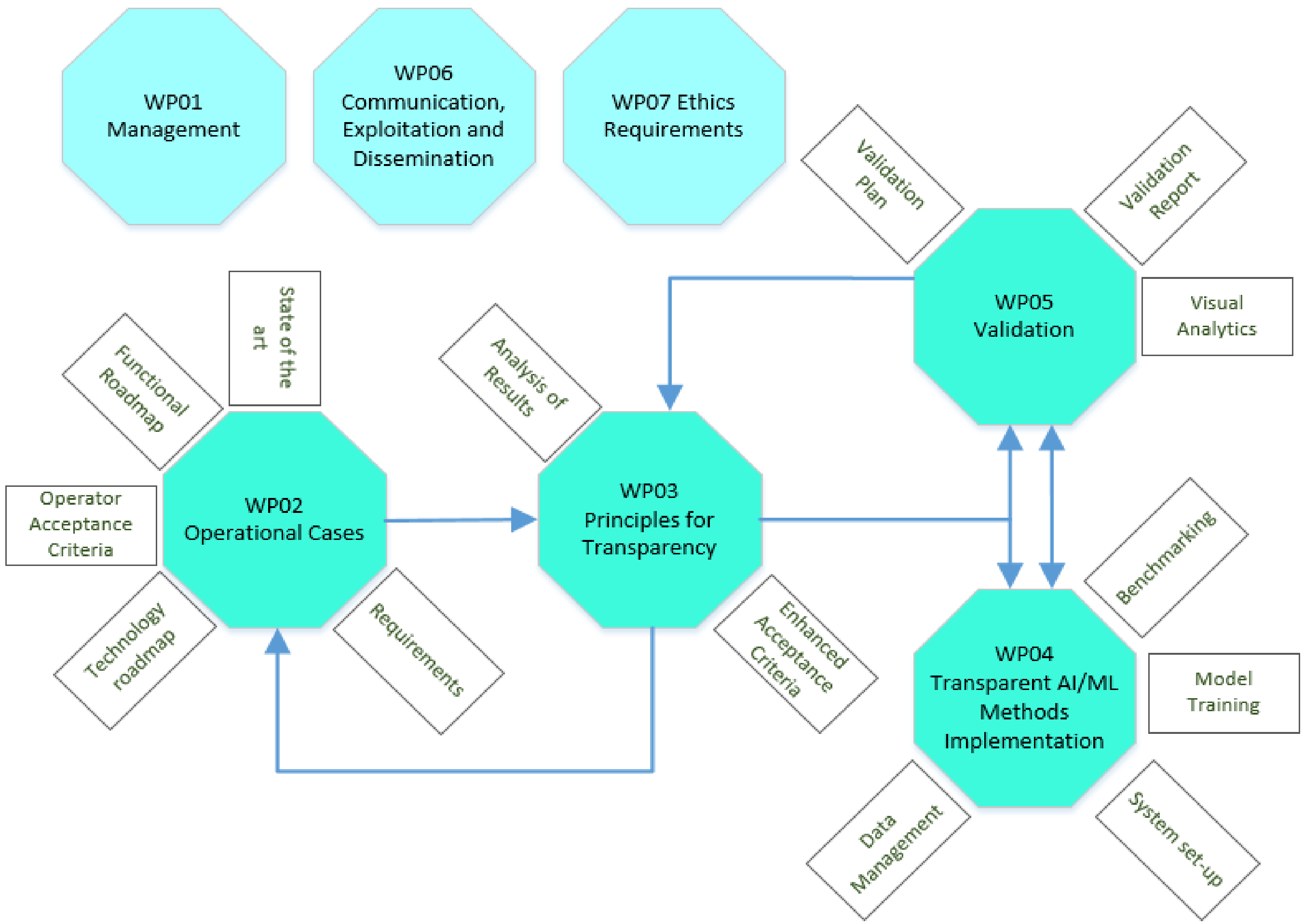
- Self-explanatory (no additional information is provided) → *The operator would understand what is proposed intuitively, based on background and expertise*
- Explainability on demand (the system may provide additional information to explain the solution reached, available if requested by the operator)
- Explainability by default (the system acknowledges the unusual condition of a solution reached and provides by default explanations on it) → *Initial intended use: training & certification*

Not all situations require the same explainability solution: actor (operator, regulator, society), context (certification, training, operation), operational context (safety-critical, strategic/planning…)

Some background (ATM trends in AI)

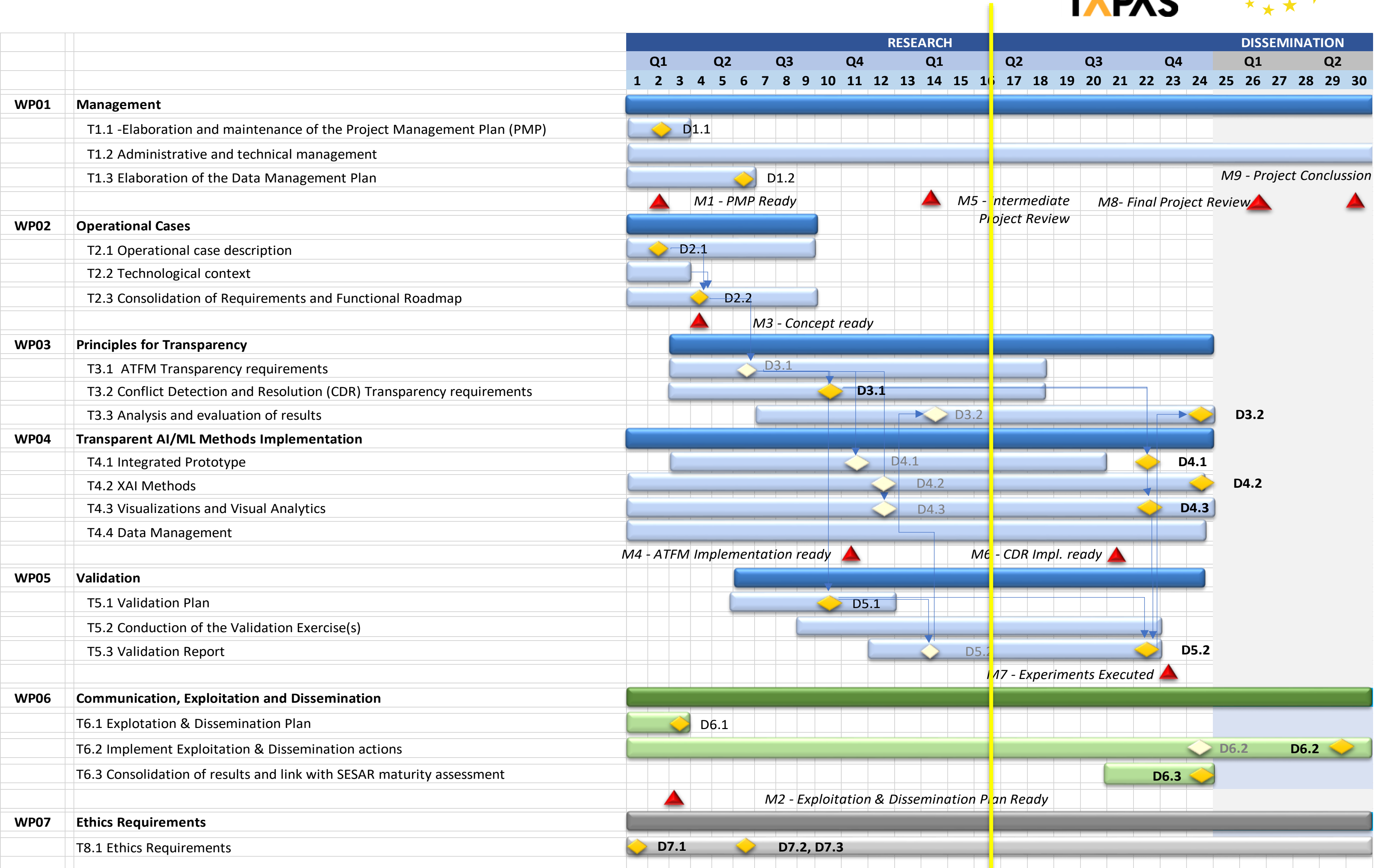


WBS

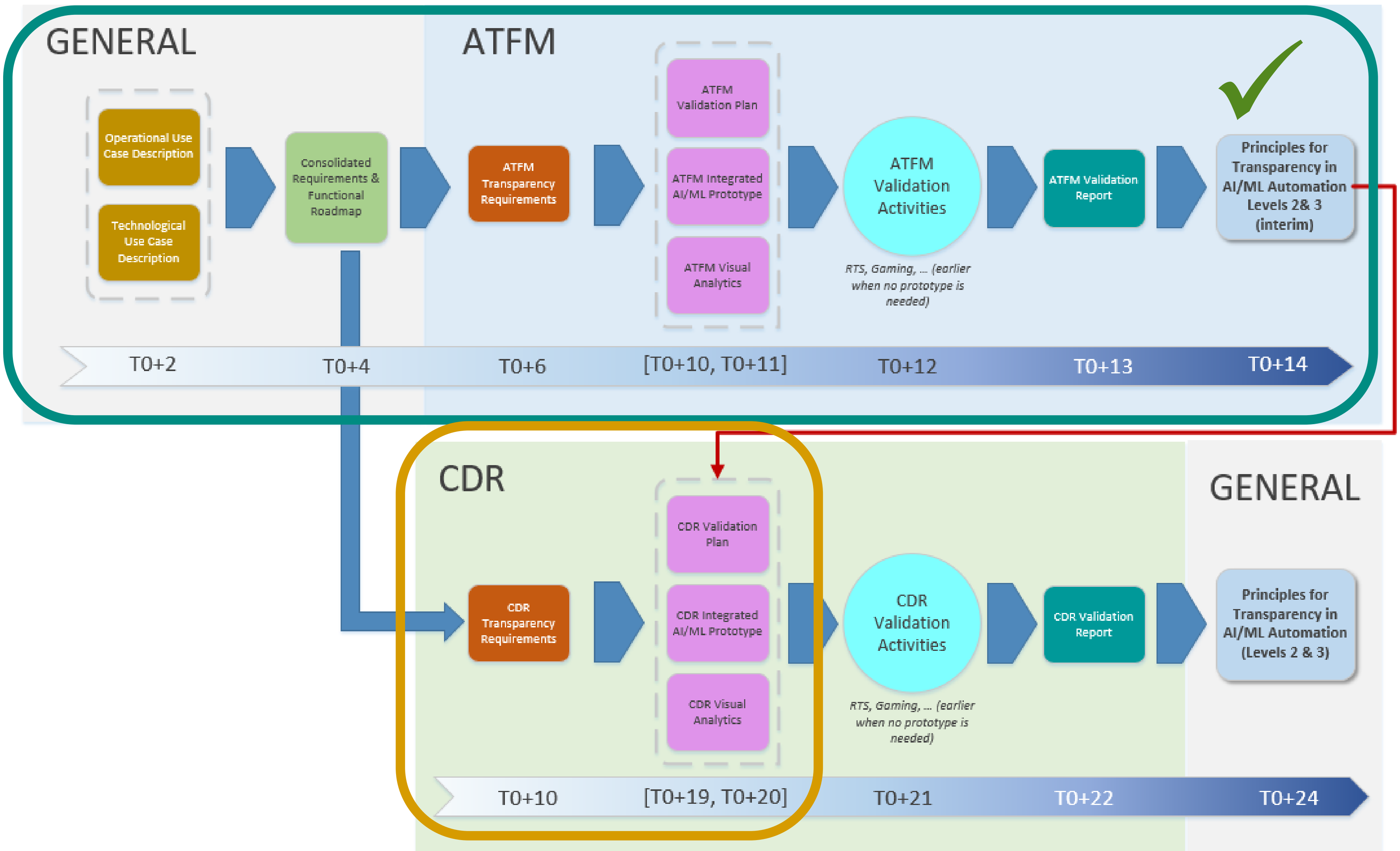


Detailed WP activities later described in this meeting, together with planning, etc…

Overall Planning



High Level Planning



Operational Staff

Participation in use case refinement + requirements
Participation in functional roadmap
Participation in validation & testing activities
Participation in workshops

Validation environments

INNOVE

Dataset

- Operational Data from ENAIRE ATC Platform (3 years of surveillance, FP + updates & sectorization data – excluding non-nominal pandemic)
- DDR (2 years ALLFT+)

Advisory Board

Franck Ballerini (ECTL)

Gilles Gawinovski (ECTL)

Marc Baumgartner (IFATCA)

Dr Luca Longo (University of Dublin)

EASA

Beatrice Pesquet (EUROCAE WG-114)

Representatives from ER4 related projects (MAHALO, AISA,…)

Events	Date	Objective
Workshop 1 ✓	Sept 2020	Provide input in functional roadmap (focus on DCB)
Workshop 2 ✓	*T0+9*	*Provide input in functional roadmap (focus on CDR)*
Workshop 3	T0+14	Share results from 1st iteration and get inputs
Final workshop	T0+24	Share final results

ATFCM Use Case - Overview

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Integrated Prototype

Single (implemented) solution with optimal selection on measures/regulations
If no solution exist then "appropriate" hotspots are declared to NM

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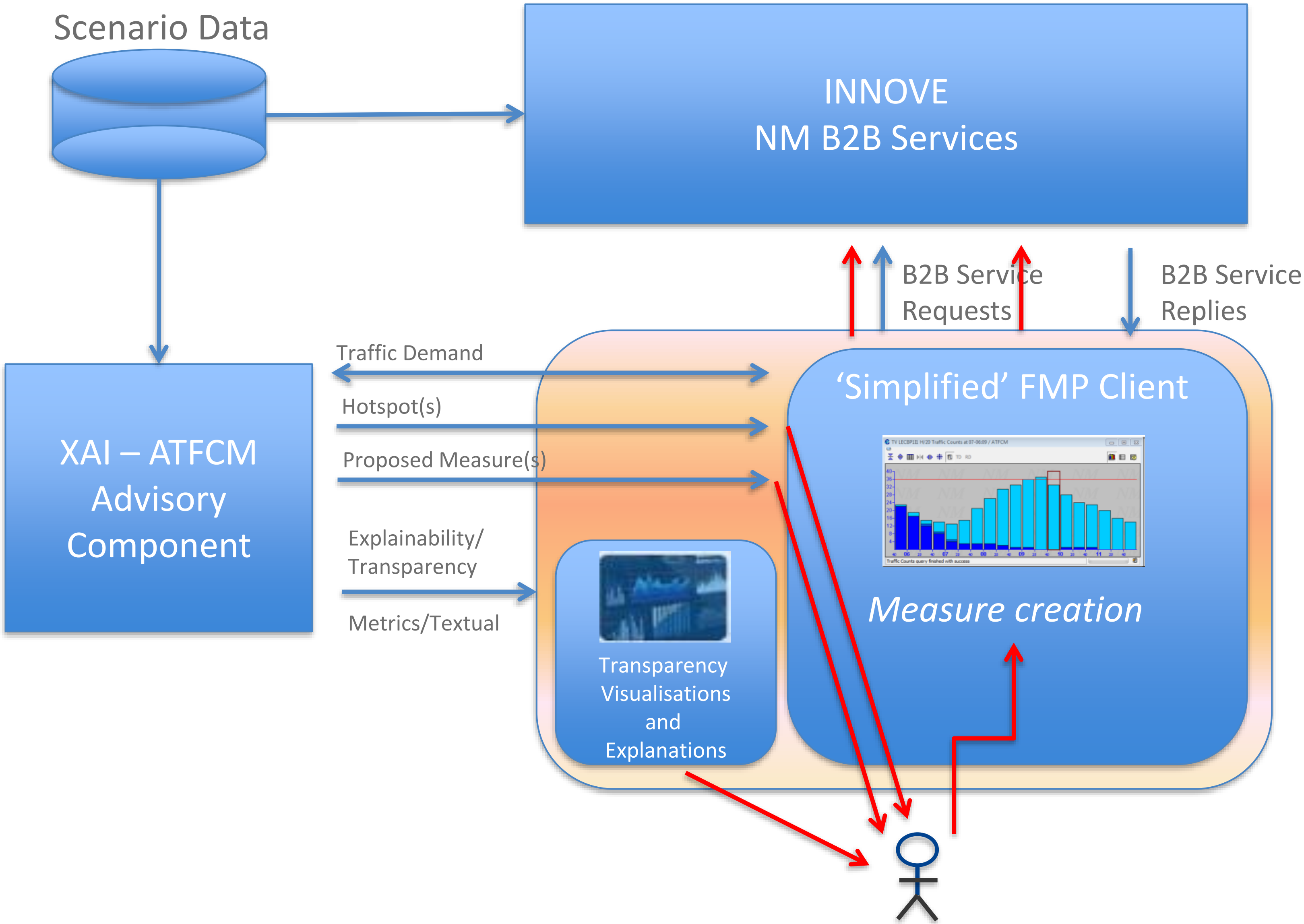
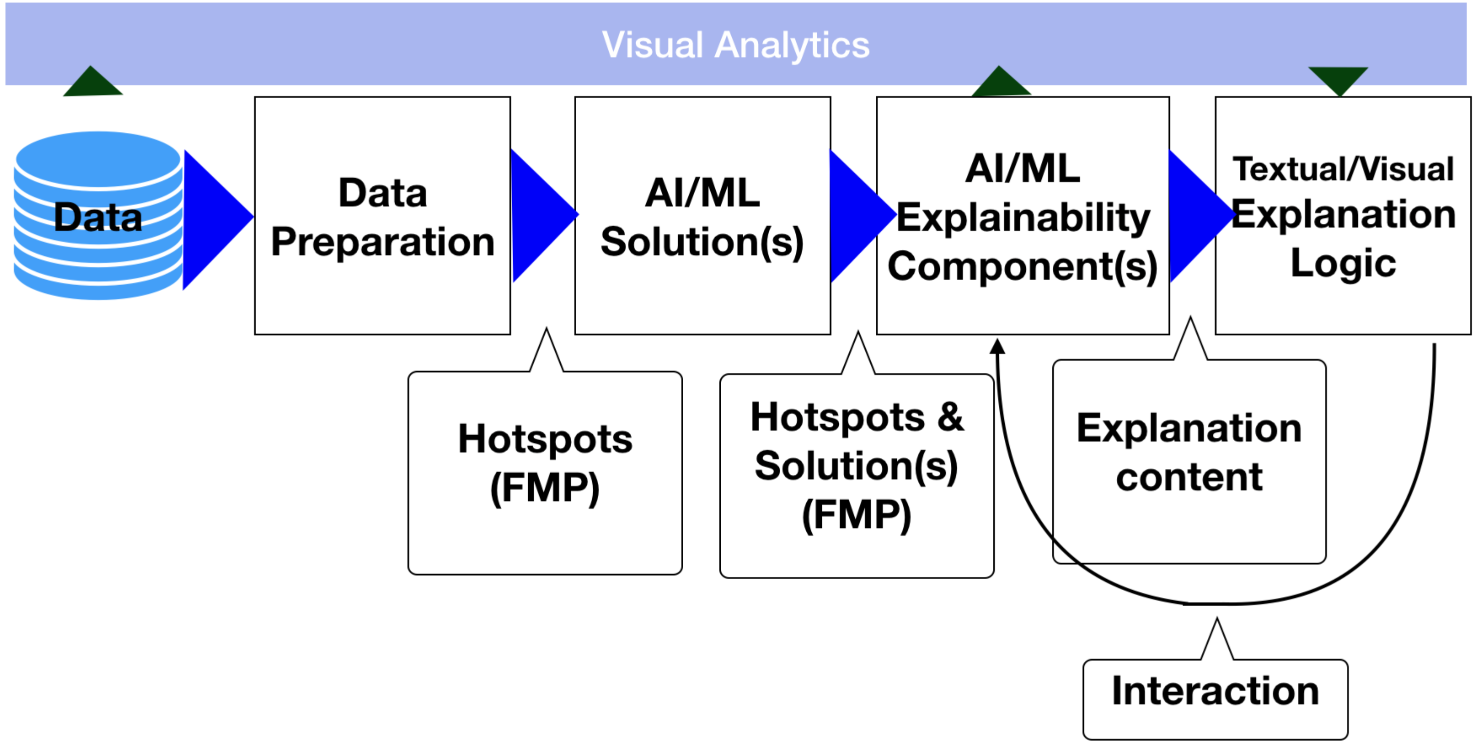
ATFCM High level ‘Technical Architecture’



Integrated Prototype

XAI Prototype System



Problem formulation & XAI methods

We consider a **multi-agent system**, where
Each aircraft executing a 4D trajectory is an agent

The **4D trajectory is a series of waypoints/sectors** crossed at appropriate times. This series for a specific flight may change due to

- **Delay at gate** up to a *MaxDelay allowed per flight*
- **Re-routing (vertical)** due to *level capping*

Different **priorities/combinations of these measures** may provide alternative solutions: *These may vary per agent*, in different ways.

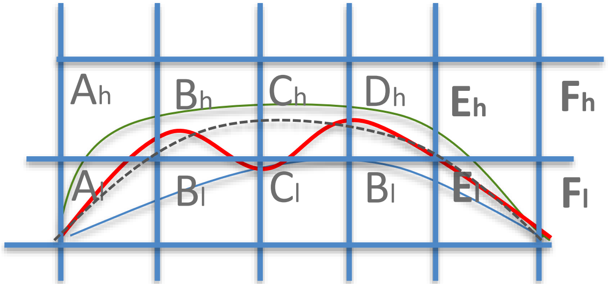
We consider **three types of flights** and **appropriate measures** to be applied:
- **Departing** from Spanish airports and **departing from close airports** (climbing phase penetrating hotspot in the Spanish airspace) (**delay and level-capping**).
- **Incoming**: arriving at Spanish airports (**delay at the origin airport**).
- **Overflights**: flying over the Iberian Peninsula (**delays at the origin airport**)

Still, the **number of allowable measures' combinations** allowed for 5K (typical single-day scenario) agents **is *very large*.**

Problem formulation & XAI methods

To prune alternatives regarding level capping, **we consider only the top-k alternative flight plans** that may result due to level capping at different sectors.

To avoid penalizing, costly and/or inappropriate level-capping measures to a single flight, we rank alternatives by the **expected rate of flight-level change in all sectors (ERFL change)**



$$ERFL(\tau) = \sum_{s:sector\ crossed\ by\ \tau} \frac{|\Delta alt_\tau^s|}{\Delta time_\tau^s}$$

Problem formulation & XAI methods

Problem Specification:

Each agent has to choose

- The **appropriate level-capping strategy per sector** (i.e. level capping options allowed by the top-k alternative flight plans) ,

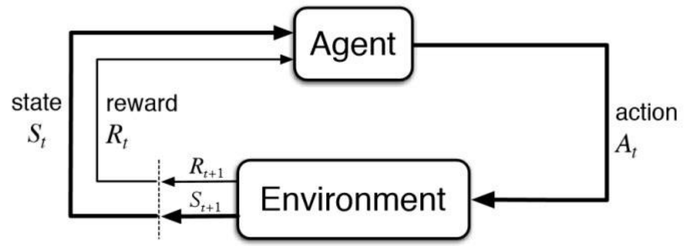
In *conjunction to*

- The **appropriate delay at gate before the take-off time**

so, as to **resolve all hotspots jointly with other co-occurring (spatiotemporally) agents**.

Problem formulation & XAI methods

Reinforcement Learning (RL) is the training of machine learning models to interact with their environment.
The model (called an Agent in RL settings) observes the State of the environment and decides upon an Action, which results in a new State and a Reward.



Deep RL is the combination of the RL framework with Deep Neural Networks.

This combination provides RL with the **robust generalization capabilities** of Neural Networks, which are **essential when the possible environment states are intractable**.

Problem formulation & XAI methods

There **are 3 main challenges** in the proposed approach

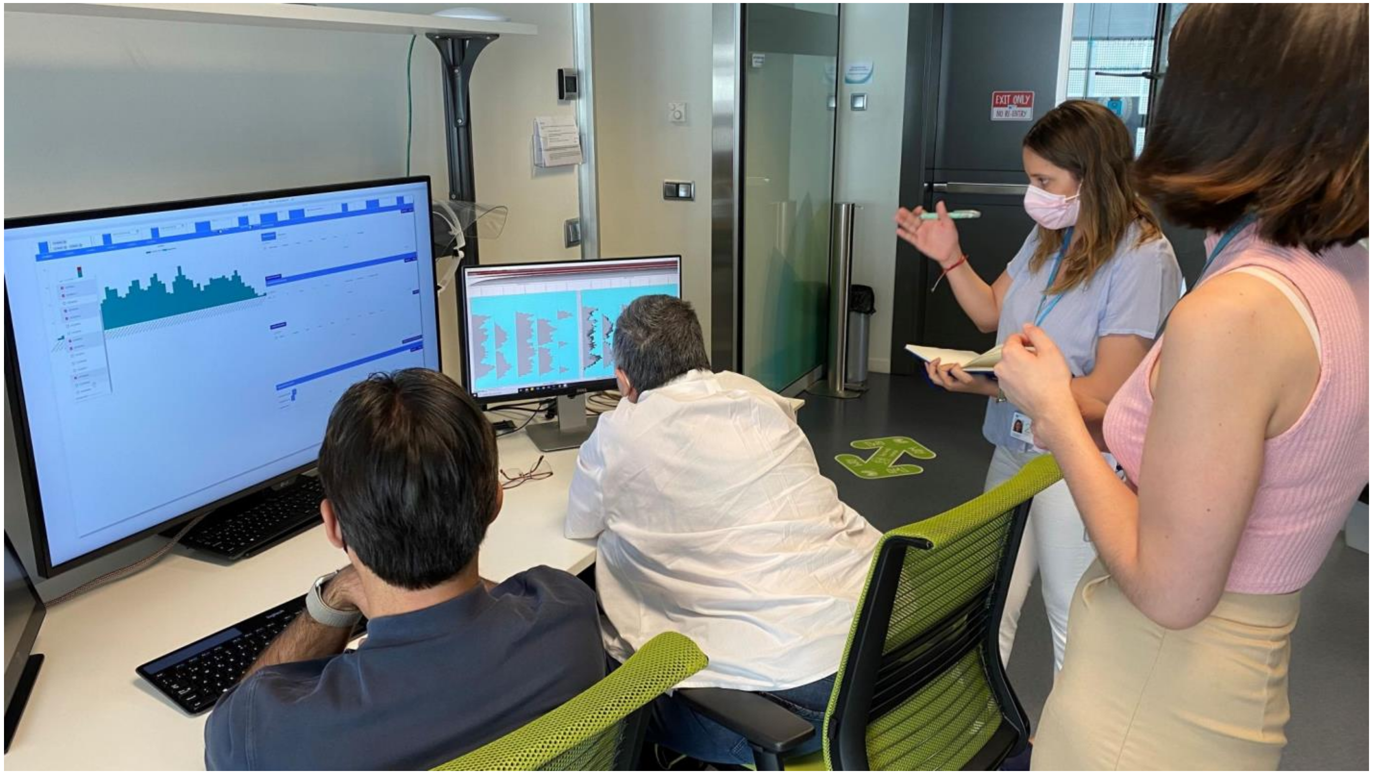
- Deep RL methods are very sensitive to **hyperparameter tuning**. This means that a certain number of experiments is needed, in order to discover the optimal parameters and achieve the best possible results.

- The **large number of daily flights, as well as their numerous interactions, pose a significant scalability problem**. For Deep RL models to capture all these intricacies careful design choices and rigorous training is needed.

- **Explainability is very much an open field of research in Deep RL**. Assessing how XAI techniques can help understand complex models has not been extensively studied.

Validation Experiment

ATFCM Validation Experiments (RTS) concluded on June, on schedule!



Middle of project activities

Time for analysis of results and preparation of the secong use case!

Initial Feedback – Oriented in three main areas

- ✓ Explainability
- ✓ *Tooling*
- ✓ Lessons learnt

Enough material to get some valuable material, in combination with the achievement of Transparency Requirements, to ellaborate a first version of transparency framework - WIP

Explainability

- **Trustworthiness** is the best explanation
- During operations: no need to see all the steps and explanations
- Training/technical environment: more need for (detailed) explanations
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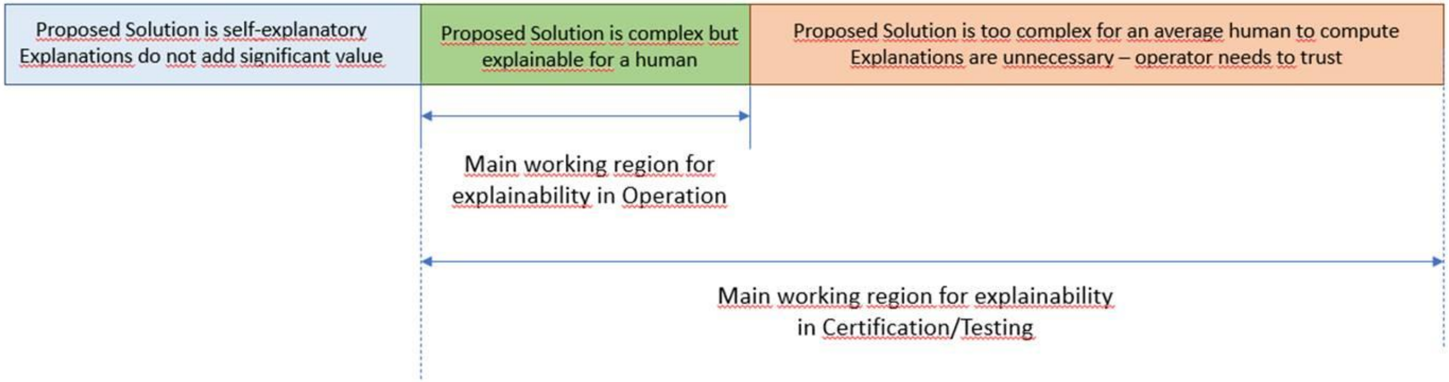

- Some solutions are too complex for a human to understand in real time

– *the added value window is limited*

Lessons Learnt

- Operating method for Level 2 must be previously defined
- Involve operational experts in the prototype design phase
- Explanations must have a clear traceability
- Focus on the solution impact (before/after) (e.g., statistics, aggregated information)
- Data coherence and integration between tools

Thank you very much for your attention

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