AI based innovation in ATM: Improving Efficiency, Trust and Safety

Final Dissemination Event
TRUSTY, CODA, ASTRA, SynthAIR, ENGAGE 2
05 December 2025 - Bled, Slovenia

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Engage 2

Engage 2
People, Ideas, and Innovation for the ATM

Marilea Laviola

Dissemination Event

Bled, 5 December 2025

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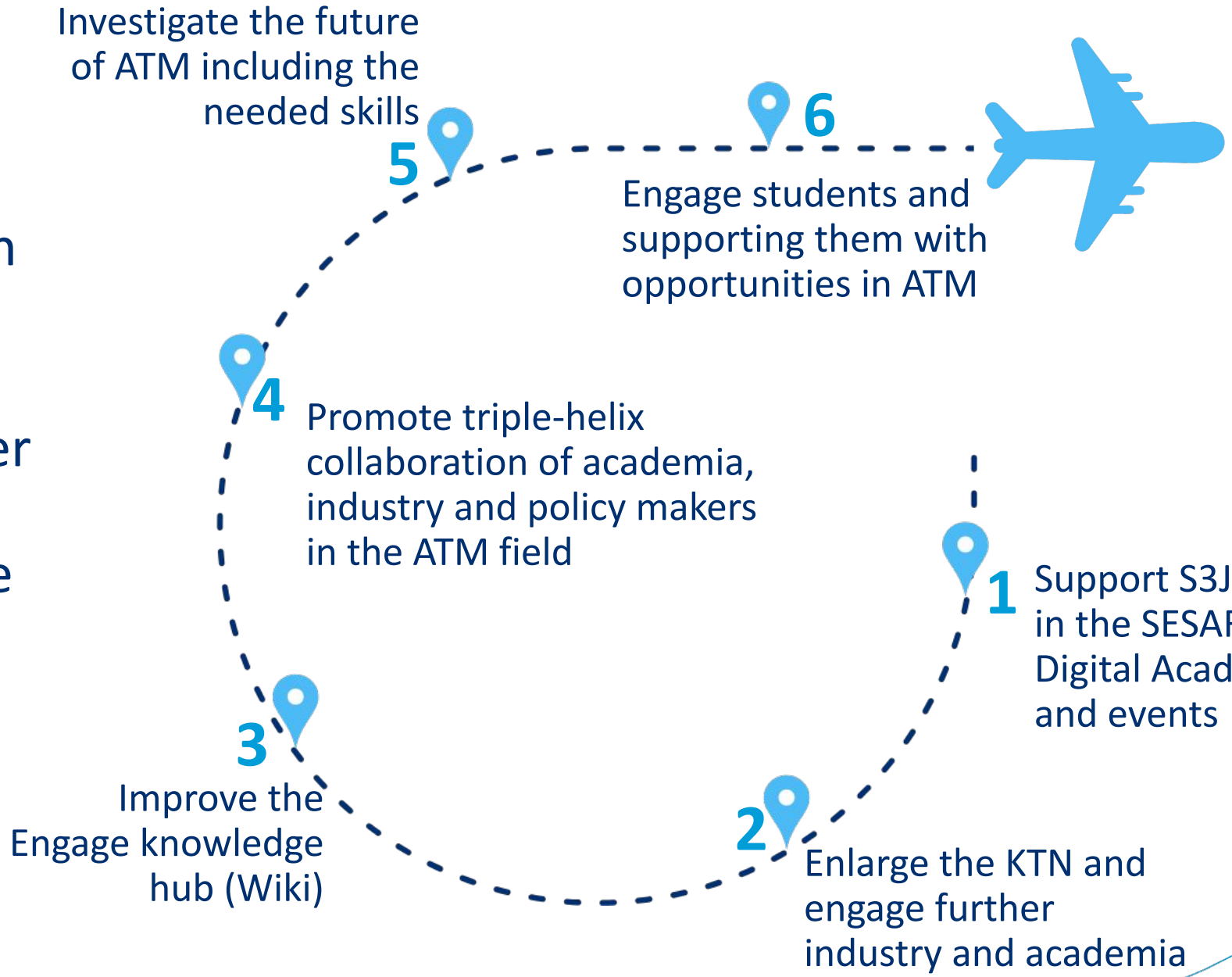
Engage 2

is the **bridge** between academia and industry in the ATM domain.

Its **mission** is to empower the next generation aviation workforce in the ever-evolving digital economy by focusing on **six core objectives:**



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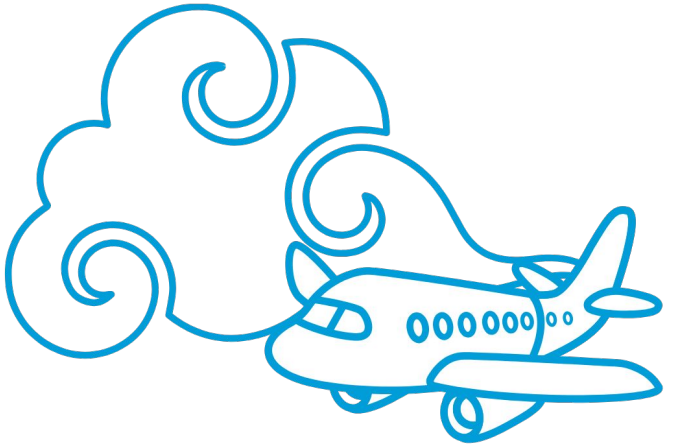

THEMATIC CHALLENGES

Challenges not already covered by SJU programme.
Based on these challenges, the Calls for PhD and Catalyst funding were and will be based.

1. Climate impact analysis&mitigation for ATM related non CO2emissions
2. Passenger-centric digital airport
3. Disruptive ATM system modernization
4. Integration of new entrants

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CATALYST FUNDS

Designed to rapidly mature exploratory research, bridging the gap between innovative concepts and industrial application within ATM.

Following the success of the first call, which funded **7 ambitious projects**, **the second wave of funding is open** to provide financial support and access to industrial collaboration environments.

Visit our website and submit your idea!

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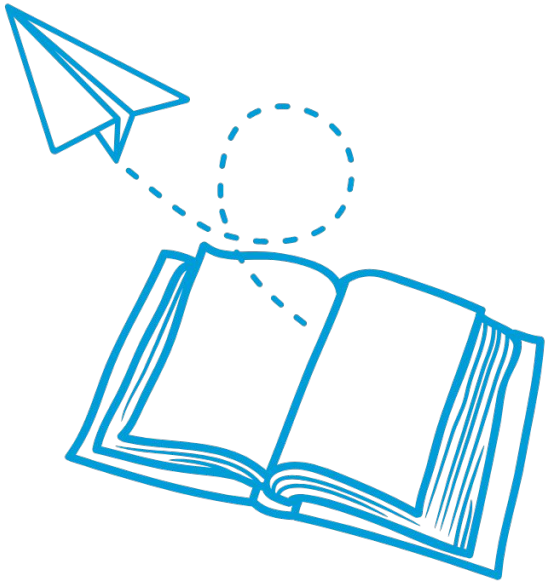
SUPPORT TO MSc STUDENTS & PhD



Student opportunities at MSc level

Support to master theses on key topics

APPLY NOW

Supervision of university professors and mentoring of consortium partners.

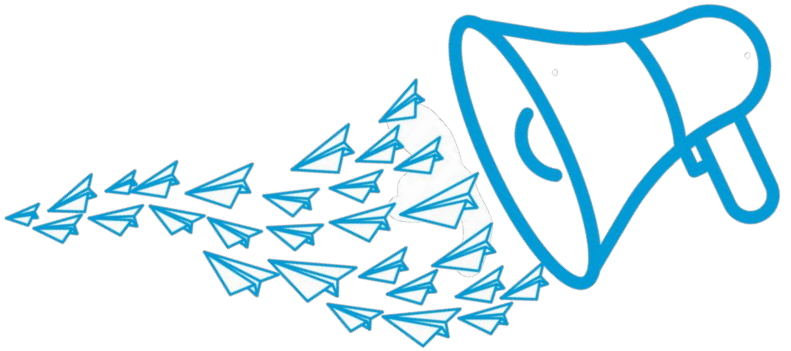
Student opportunities at PhD proposals

Call launched in April 2024 = **8 funded PhDs**

Aimed at developing research ideas and contributing significantly to the evolution of the Eu ATM system.

Funded PhDs receive financial support and learning opportunities through summer schools and workshops.

Engage 2



WORKSHOPS AND EVENTS

- **Thematic workshops and webinars** to convene stakeholders and delve into specific project challenges.
- **Thematic workshops** on the identified thematic challenges.
- **Cross-fertilisation/flagship workshops** to foster coordination with other domains and SESAR different flagship.

Next event at the Athens Airport on February 24th!

Engage 2

WIKI

The Engage 2 go-to hub for ATM research. It allows you to:

- explore innovative projects
- gain industry insights
- stay updated on EU events and initiatives
- access learning and professional opportunities in ATM.

MATCHMAKING APP READY TO TEST!
REACH OUT IF YOU WANT TO BE PART OF IT!

Visit at wikiengagektn.com

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OPEN DAYS

Engage 2 organises three open days with a number of parallel events in different academic institutions across Europe:

- **Open Day #1 |** March 2024 at Airspace World in Geneva
- **Open Day #2 |** October 2025 at EASN International conference in Madrid

SUMMER SCHOOLS

3 summer schools organized by Engage 2:

- **Winter School in Belgrade** 27-31 January 2025
- **Summer School in Braunschweig** in 22-26 September 2025
- **Next Summer School** will be in September 2026 **in Trieste**

Stay tuned for the next dates!

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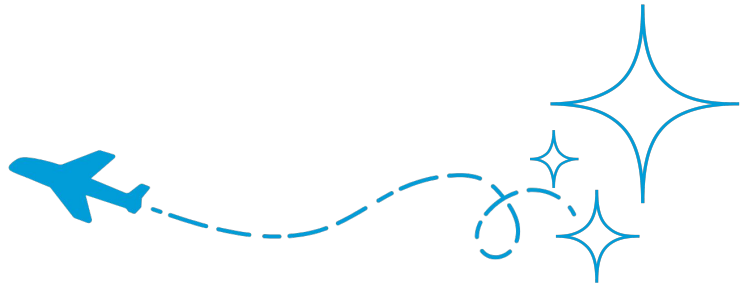

JOB CARDS AND VIDEOS

A set of interactive cards and videos featuring ATM job descriptions, required qualifications, average salaries, and inspiring stories from professionals who share why they love it.

HACKATHON

Two days to tackle the ATM challenge, featuring a collaborative coding session.
The first was held in Madrid on the 24th and 25th of March 2025.
Following one in Autumn 2026 jointly with AWARE and DIALOG!

Following one in Autumn 2026 jointly with AWARE and DIALOG!

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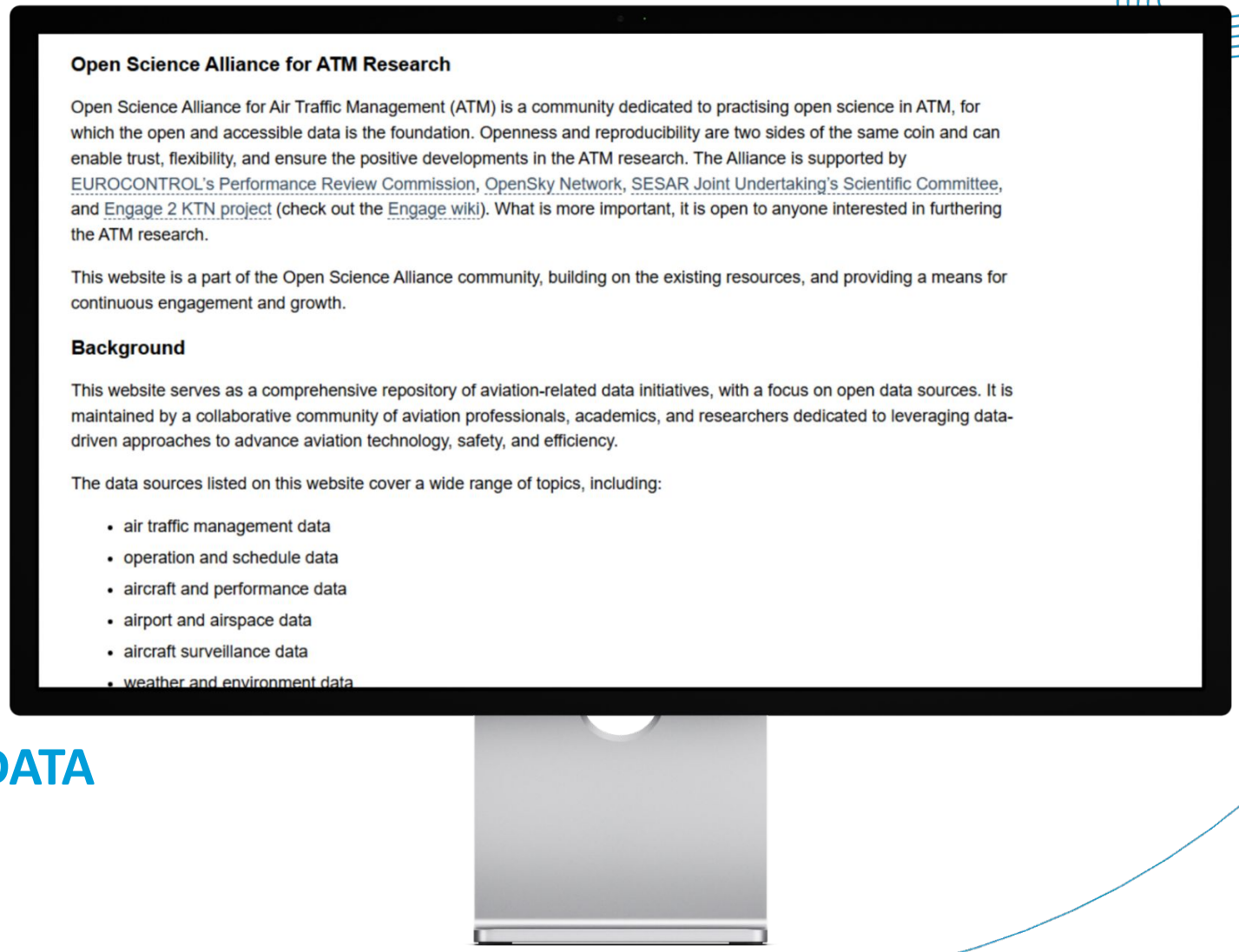
Engage 2 Open Science Alliance for ATM Research

Engage 2, EUROCONTROL's Performance Review Commission, OpenSky Network and SJU's Scientific Committee support the initiative.

You can find data sources and open tools.



READ MORE ON OUR WIKI
ROADMAP AND RESOURCES < OPEN DATA

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Engage 2

How can you stay tuned about Engage 2?

Engage 2 Wiki

LinkedIn

Newsletter

Engage 2

THANK YOU FOR
YOUR ATTENTION!

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Engage 2

An AI-augmented roadmap for aviation

Gérald Gurtner, Andrew Cook, Graham Tanner,
University of Westminster, London

Engage 2 Workshop Dec. 2025

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Engage 2 Case study: building a roadmap for SESAR

- Goal: provide a set of concepts extending beyond SESAR 3 to build a high-level roadmap for the European aviation system.
- Information on:
  - R&D topics,
  - Concepts
  - Challenges,
  - Priorities
  - Existing research initiatives.
- Builds on work from Engage 2 about trends for workforce skills

Engage 2 GenAI for a roadmap

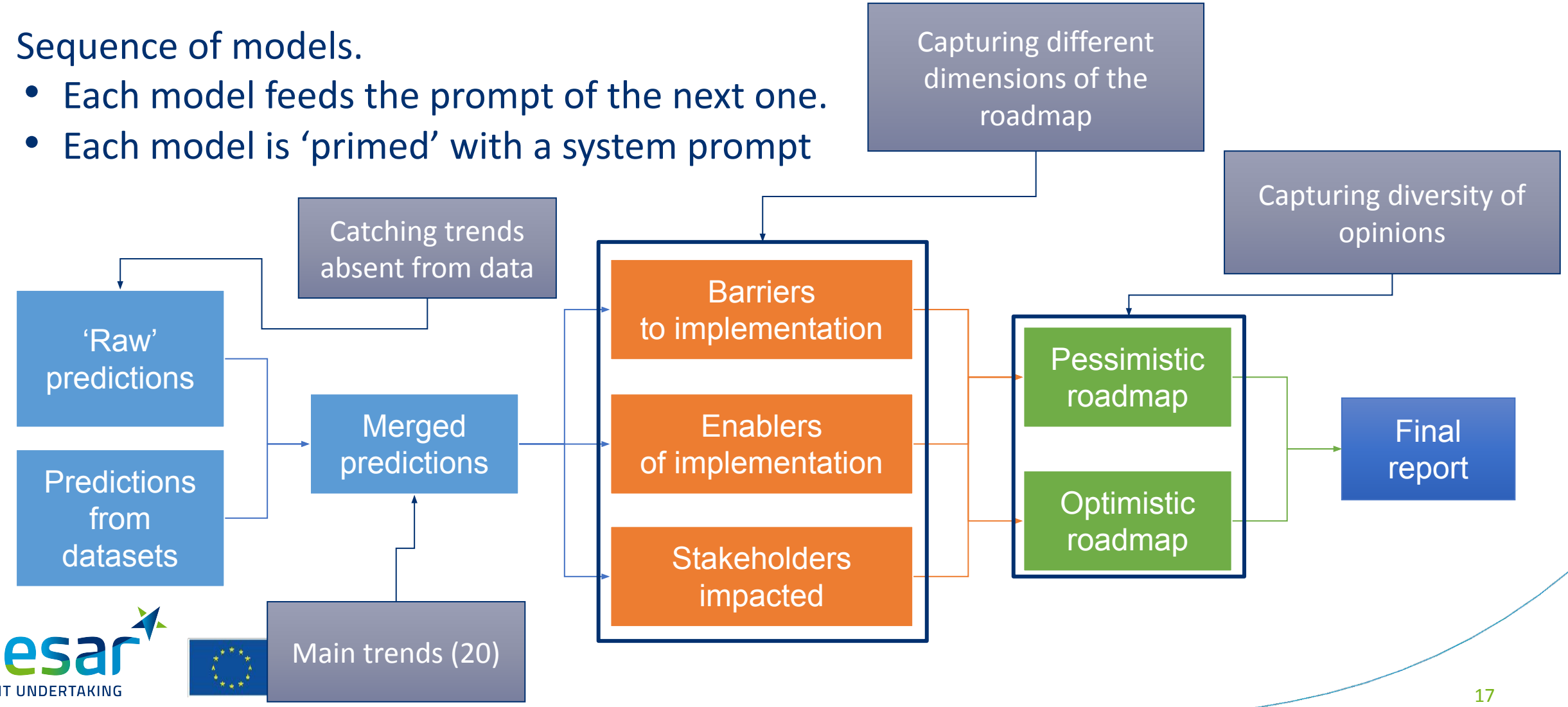
- Use GenAI to:
- ingest many documents related to the topic (summary)
- infer topics (soft clustering)
- flag challenges and opportunities (semantic analysis)
- forecast development (making links between different topics)

See QR code at end for our survey and a link to first version of del (D5.1): sequential models, with full description

Engage 2 Methodology

Sequence of models.

- Each model feeds the prompt of the next one.
- Each model is ‘primed’ with a system prompt



Engage 2 Data sources

Material sourced*

- Conference papers (>300):
  - SIDs (2024)
  - ATM Seminar (2021, 2023)
  - ICRAT (2020, 2022, 2024)
- Project reports (>200):
  - SESAR 2020 (ER4, IR Waves 2/3)
  - SESAR 3 (ER1, IR1 - *to date*)
- Reference documents (≈10):
  - Master Plans and SRIAs (SESAR, Clean Aviation, Europe's Rail)

Planned material

- Conference papers (≈100):
  - SIDs (2025)
  - ATRD[¶] Symposium (2025)
- Project reports (TBC):
  - SESAR 3 (ER1, ER2, IR1 - *future reporting*)
  - other projects of potential interest (including Clean Sky 2, Clean Aviation, EASA, CINEA, broader Horizon Europe)

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* Excludes material which has previously been analysed, either as part of D4.1 or by Engage 1

¶ US-Europe Air Transportation Research & Development

Engage 2 Results

- A few selected trends and enablers
- Qualitative assessment by humans reveals quite a good coverage (but see validation issues later), except maybe for hydrogen technologies.
- Links between trends, enablers, barriers, etc were all relevant, though some of them are a bit generic.

Trends	Key enablers		
	1. Technology & infrastructure	2. Gov. & regulatory support	3. Investment & collaboration
Electrification & advanced battery technologies	Advancements in battery tech.; charging infrastructure	Policy; emissions regulation	R&D investment; aero-battery collaboration
Synth. fuels & direct air capture integration	Electrolysis; renewable energy; carbon capture tech.	Government policies; carbon pricing	Infrastructure & supply chain investment
Unmanned freight & cargo drones	Autonomous navigation; battery tech.; communication	Regulatory framework; airspace integration	Cost-effective manufacturing & scalability
On-demand, personalised air travel	eVTOL technology; urban infrastructure	Regulatory framework; ATM integration	Booking platforms
Quantum computing-optimised ATC	Quantum hardware; communication networks	Regulatory & standardisation frameworks	Integration with classical ATC

Engage 2 Focus on quantum computing

Barriers

- Quantum Hardware Limitations
- Algorithmic and Software Development Challenge
- Integration with Existing ATC Infrastructure
- Regulatory and Safety Certification
- High Costs and Resource Requirements

Enablers

- Advanced quantum hardware development
- Quantum Algorithms for Optimization and Conflict Detection
- Integration with classical systems and infrastructure
- investment in quantum research and ecosystem collaboration
- regulatory frameworks and standards for quantum technologies

Logistics and cargo companies: will benefit from more precise tracking and optimized routing, enabled by quantum-enhanced positioning and data processing, improving delivery times and supply chain reliability

Engage 2 Next steps

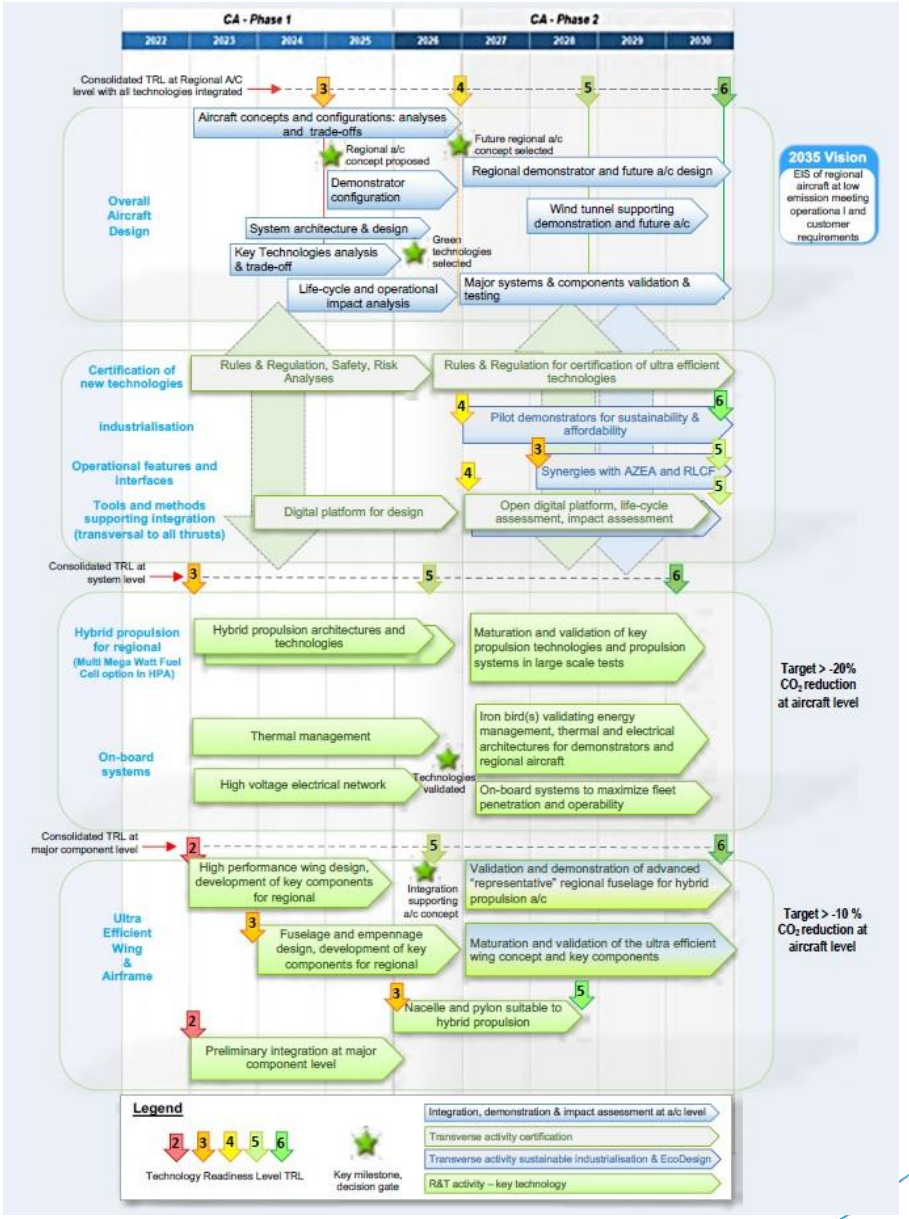
In Engage 2:

- integration in Engage 2 wiki
- formatted roadmap(s)
- phase 2: agentic system
- more input sources

https://wikiengagektn.com/

Beyond Engage 2 (?):

- chatbot to ask questions on results & documents
- very weak signal discovery:
  patent, social media posts, general news



Clean Aviation SRIA (2024)

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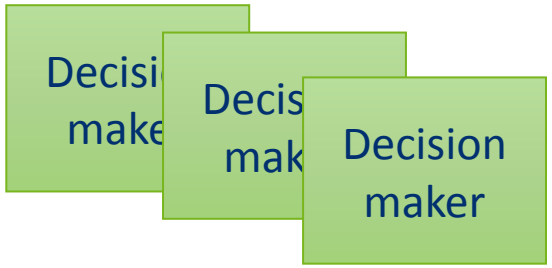
Engage 2 Step back: what is a roadmap?

- A roadmap is a highly strategic document, blending:
  - Forecast (what is feasible and when?)
  - Political will (where do we want to go?)
- In reality, roadmaps are built by intensive rounds of iterations between experts and decision makers. They require:
  - Knowledge compilation,
  - Abstraction,
  - Intuition on the system,
  - Forecasting tools,
  - Holistic view of the system (and beyond),
  - Policy motivation…

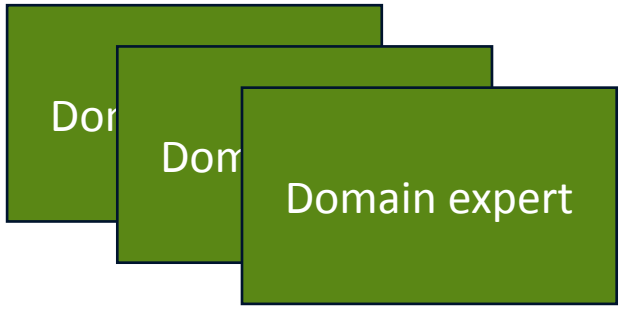
 social interaction, consensus, and cooperation is key to (human) strategic roadmaps. Let's do the same with AIs!

Engage 2 A possible agentic architecture

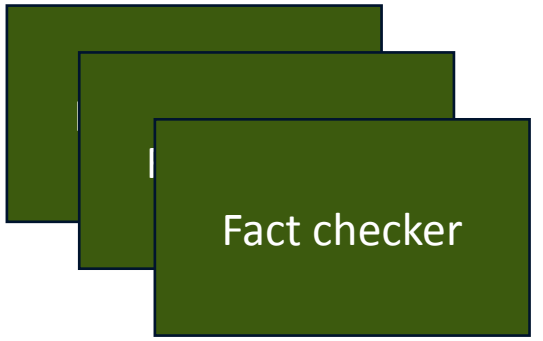
- Highly self-reflective
- Sets high-level goal
- Creates strategy for roadmaps (?)
- Facilitates discussion
- Creates agents if needed



- Primed with different behaviours
- Consensus-formin g swarm
- Can form committees of expert, ask for reviews, ask for contradicting opinions



- Can be created dynamically
- Have access to their own dynamic RAGs for efficiency
- Can be assigned roles (related to enabler, barriers, timeline, ranking, reviews, etc)



- Low-level AI looking for facts on demand
- Produces standardised references to documents

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Engage 2 Transversal opportunities in IR2

- Automates extraction of high-level insights from large SESAR/ATM documents
- Connects performance, architecture, and solution elements
- RAG-based automatic reviews + chatbot for project support and guidance (PEARL and AMPLE3)
- Hybrid setup:
  - Static LLM for knowledge extraction
  - Dynamic AI agents for report reading, expert querying, and consensus building
- Key requirements:
  - Low hallucinations (checked via shadow-mode validation)
  - Confidentiality via local open-source models
- Enables IR2 validation and aligns SESAR with wider public- and private-sector AI adoption

Engage 2

Link to survey

Thank you

Suggestions and comments welcome!

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Innovative Solutions for AI in Aviation!

Chairwoman – Martina Ragosta, SINTEF Digital, Norway

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FINAL DISSEMINATION EVENT

AI BASED INNOVATION IN ATM:
IMPROVING EFFICIENCY, TRUST AND SAFETY

05.12.2025
09:00 AM - 14:00 PM

Engage 2 Event **introduction** and **transversal activities in SESAR**

Section 1: Innovative solutions for AI in aviation

TRUSTY **Explainability** and **Human Acceptance** for Remote Towers ATCOs' AI Tools — **09:30-11:00 AM (HYBRID SESSION)**

CODA **Predictive adaptive** human ai teaming for enroute ATCOs

ASTRA AI-Driven **Complexity Prediction and Resolution** for Flow Managers

SynthAIR **Synthetic data** to overcome the problem of data scarcity

Each topic will be examined interactively, allowing participants to indicate potentialities and challenges.

BREAK — **11:00-11:15 AM**

Section 2: Interactive discussion

- Per each relevant topic: **challenges, opportunities and impact** — **11:15-12:15 AM (HYBRID SESSION)**
- Where do we go from here? Next **hot topics**

LUNCH AND DEMOS — **12:30-14:00 PM**

Explainability and how remote tower

Diving into **adaptive human–AI**

Predictive AI helps flow managers

Showing how **synthetic data** can save us when real data is rare, messy, or simply locked behind a firewall somewhere.

…with your help, both in the room and online,
we'll make this a lively start to the day!

Let's begin!

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TRUSTY

AI Explainability and Trust, in the Remote Digital ATM Tower

- Prof. Mobyen Uddin Ahmed, Mälardalen University
- Dr. Elizabeth Humm, Deep Blue Srl.

Bled, Slovenia, *5th of December* 2025

EUROPEAN PARTNERSHIP

Co-funded by the European Union

SESAR Solution <APSARA>

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TRUSTY

0434

APSARA (AI-Powered Situational Awareness for Remote Airfields)

Partners:
MDU, Deep Blue,
ENAC, UNIROMA1

TRUSTY

Solution definition:

TRUSTY will investigate, developed, and validate a mockup of a future AI system simulating a Remote Digital Tower environment. The TRUSTY solution, named APSARA (AI-Powered Situational Awareness for Remote Airfields) extracts data on features associated with several conditions at the remote airfield. This data has been gathered through airfield video and ATC/cockpit audio communication exchange. This data is processed through multimodal machine learning algorithms, to detect and notify the ATCO of situations with increased risk, such as wind shear or a runway incursion.

With the addition of this AI capability, several feeds of data are integrated to provide the ATCO with a single, informative output. This will support increased situational awareness at the remote airfield and any risk associated with it. Thus, enabling the ATCO to manage aircraft movements with increased safety, effectiveness, and timeliness, according to the very specific conditions at the remote airfield.

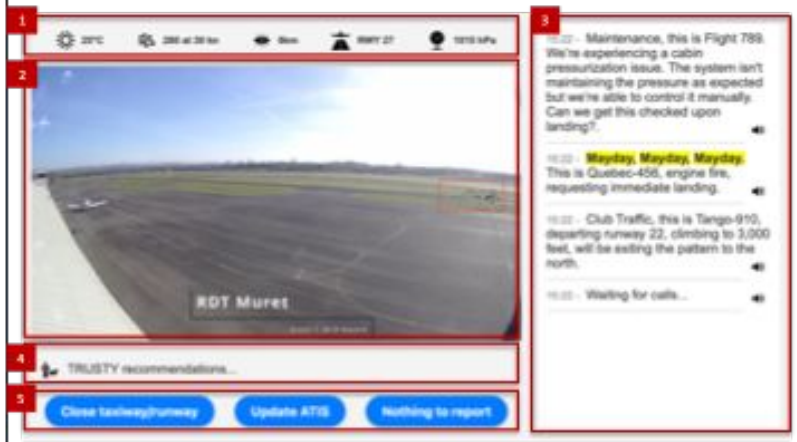
The TRUSTY solution also integrates the concept of trust as a key enabler for safe and effective Human-AI teaming. Within the APSARA prototype, neurophysiological measures—including EEG and EDA—are employed to monitor operator states related to workload, stress, vigilance, and acceptance. These indices are used to assess and model trust dynamics during interaction with the AI and to inform the adaptive behaviour of the system. In the current phase, physiological monitoring supports validation and proof of concept; in future R&I phases, it will enable real-time, trust-aware adaptation of HMI transparency and AI explainability, enhancing both user confidence and system resilience.

Supporting Solution Validation Exercises and dates:

- TVAL.10.1 Deep Blue - ENAC, France - Students and professional ATCOs 2024-09-01 to 2025-06-30

TRL1 | TRL2 | TRL4 | TRL6 | TRL7/8 | Target Release R15

31/08/2025



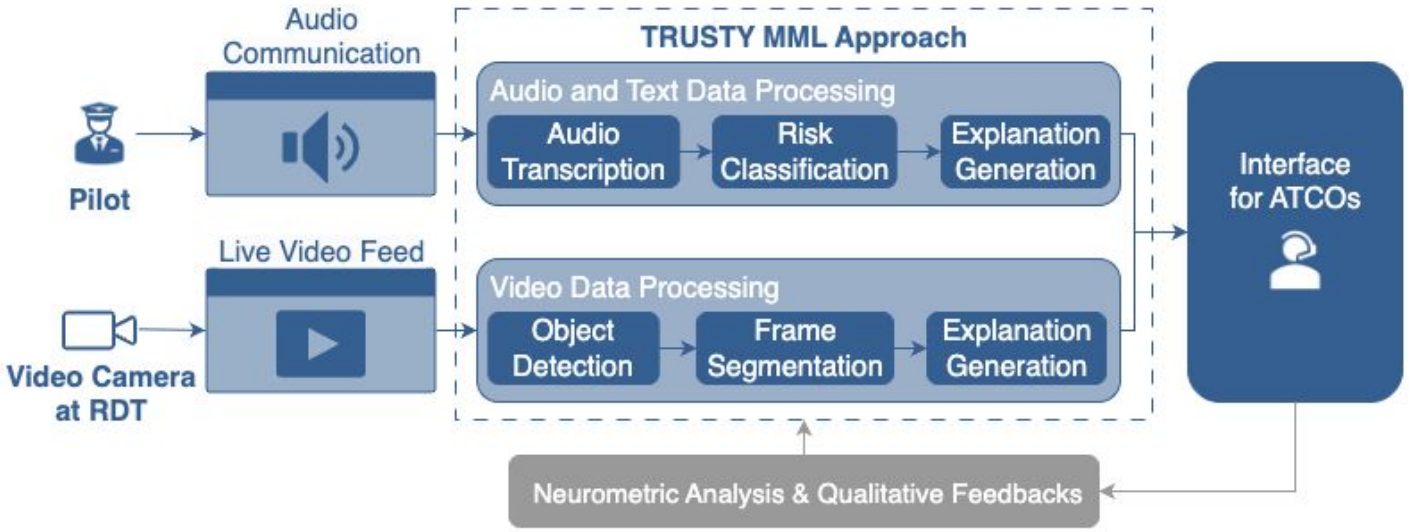
List of KPAs addressed – Environment (ENV), Capacity (CAP), Operational Efficiency (OPS), Security (SEC), Safety (SAF), Human Performance (HP)

Implementation of the AI tools

TRUSTY

Multimodal Machine Learning Solution

- Diverse data modalities
- Incorporate robustness, transparency, and fairness
- A proof-of-concept demonstrates the potential of multimodal AI systems in RDT



Implementation of the AI tools

Multimodal Machine Learning Solution

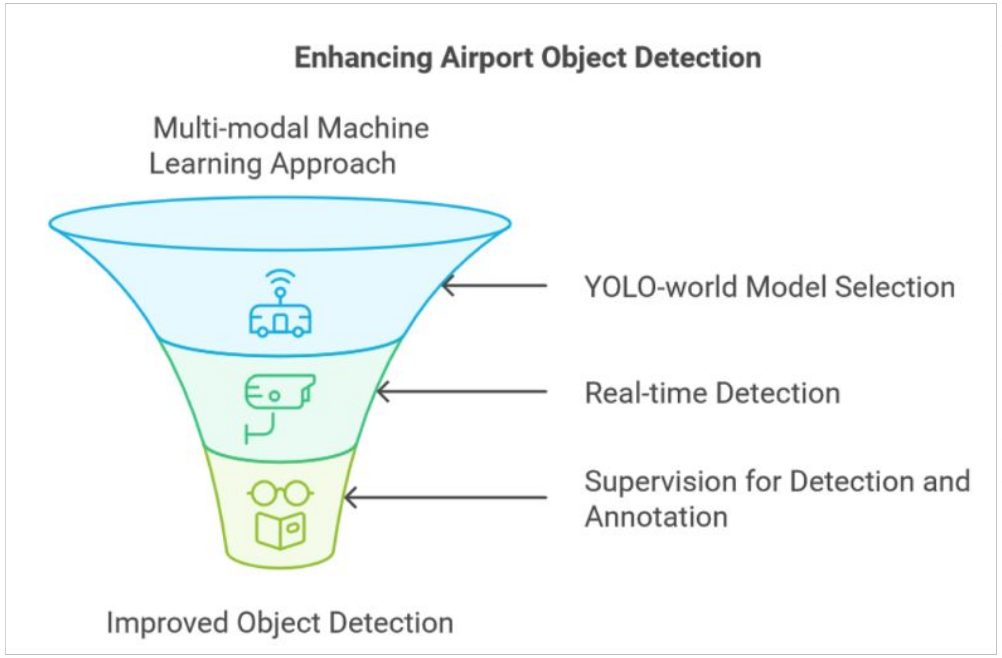


Fig. Workflow of object detection from video data

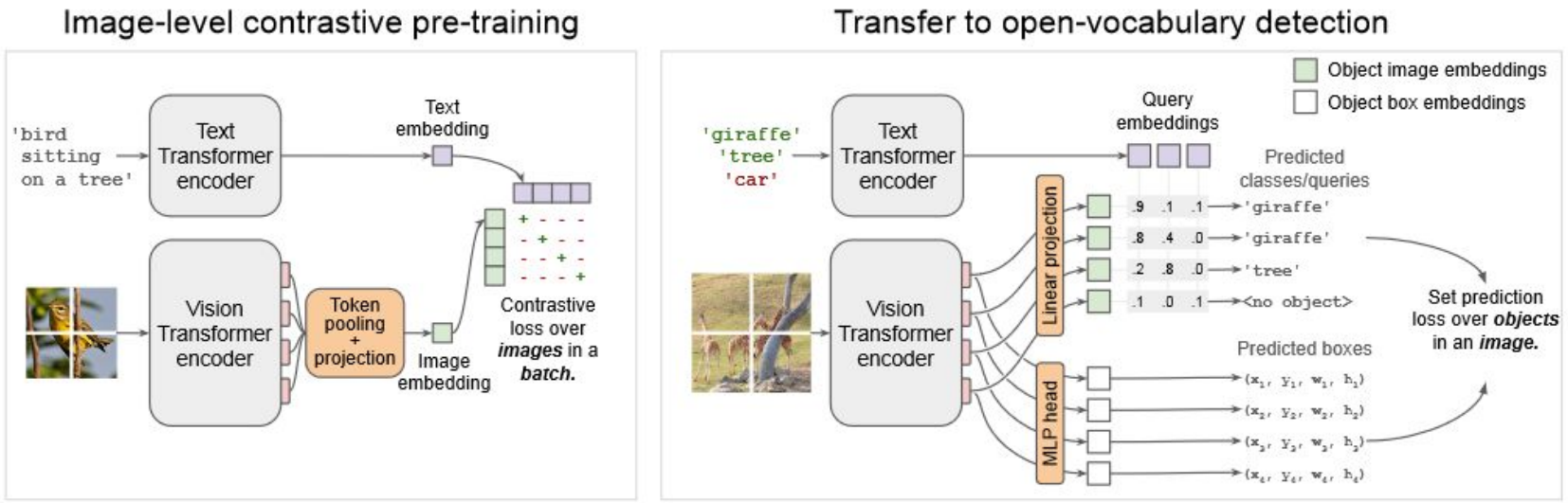
Rule-based Approach:

- Spatial Constraints — Detecting objects only within a specific region, e.g., detecting aircraft, animals, or vehicles only within a designated zone.
- Object class Constraints — Detecting specific types of objects, e.g., detecting only aircraft.
- Temporal Constraints — for effectively tracking objects to be present for a certain duration in the scene.
- Environmental Constraints — specific conditions are ignored for detections, e.g., low light, occlusion, etc.

Implementation of the AI tools

Multimodal Machine Learning Solution

- **Video data**
  - **Open-Vocabulary Detection Task (YOLO-World)**
  - Vision Transformers (ViT)
  - Yolo Real-Time Detection Transformer (RT-DETR)



Implementation of the AI tools

Multimodal Machine Learning Solution

Example of events and rules

Event	Condition	Dangerous Case	Non-dangerous Case
An aircraft stopped on the runway	No other objects on the runway except an aircraft.	If the aircraft stopped for >=threshold seconds on the runway then the bounding box is Red.	If the aircraft is staying at the edge of the runway or the aircraft is moving or the aircraft holding short (<threshold sec) of the runway then the bounding box is Green.
An aircraft lands and stops on the runway	No other objects on the runway while an aircraft is landing.	If the aircraft stops for => threshold seconds either on the runway or at the threshold between runway and taxiway then the bounding box is Red.	If the aircraft is moving or the aircraft initiates a go-around then the bounding box is Green.
Birds or Drones present at the runway threshold	The runway is empty, or an aircraft on the runway, or an aircraft wants to land	If there are folks of birds or drones at the threshold of the runway then the bounding box on the birds, drones and/or aircraft on the runway is Red.	If the birds or drones are away from the threshold or birds or drones flying high in the sky then the bounding box on the birds, drones and/or aircraft is Green.
Vehicle, animal or human on the runway	There is a vehicle, animal or human on the runway. There is an aircraft on the taxiway that wants to takeoff, or an aircraft wants to land	If there is a vehicle, animal or human on the runway (moving/stopped) then the bounding box on the vehicle, animal or human and/or aircraft is Red.	When the vehicle, animal or human exits the runway to a safety margin then the bounding box on the vehicle, animal or human and/or aircraft is Green.
A smoke or fire event near the runway	There is smoke near the runway, and there is an aircraft that wants to land. Or, there is an aircraft catching fire and smoke.	Because of smoke, there is low visibility, so the bounding box of the smoke area is Red. In the case of an aircraft on fire bounding box of that aircraft is Red.	If the smoke is outside some threshold distance, the bounding box of the smoke area is Green.

Implementation of the AI tools

Multimodal Machine Learning Solution

- Object Detection

Implementation of the AI tools

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TRUSTY

Multimodal Machine Learning Solution

- Object Detection

Object labeled and Explainablity with confidence score*

Distance measurement between object using Open CV

Non - Dangerous Event

Dangerous Event

Implementation of the AI tools

Multimodal Machine Learning Solution

Attention method

All objects detected are shown

All objects are shown with the bounding box

Only objects that are likely to have safety implication are shown of explanation of why it's being shown

Implementation of the AI tools

Multimodal Machine Learning Solution

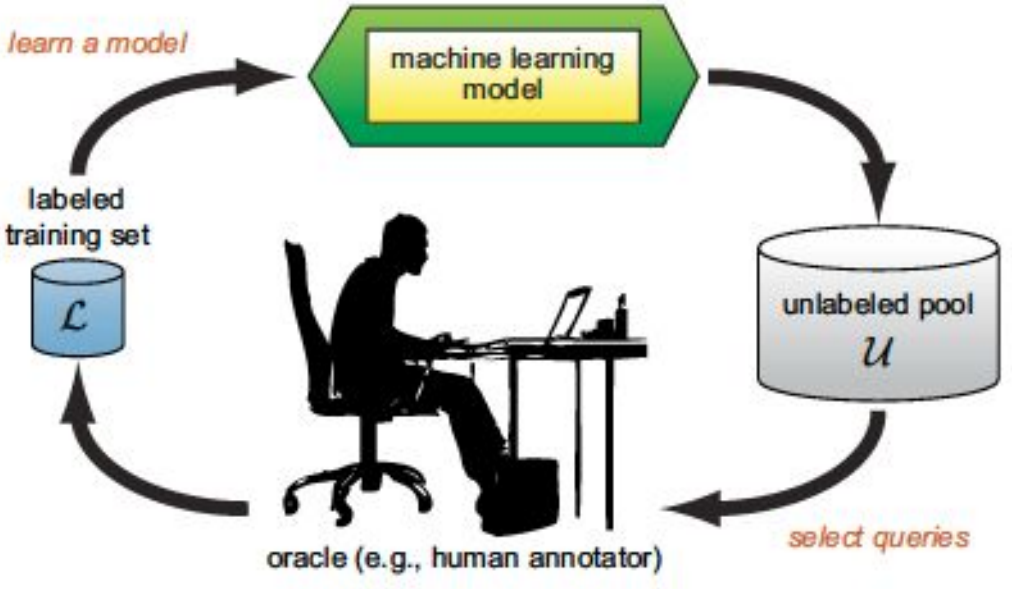


Figure: The pool-based active learning cycle

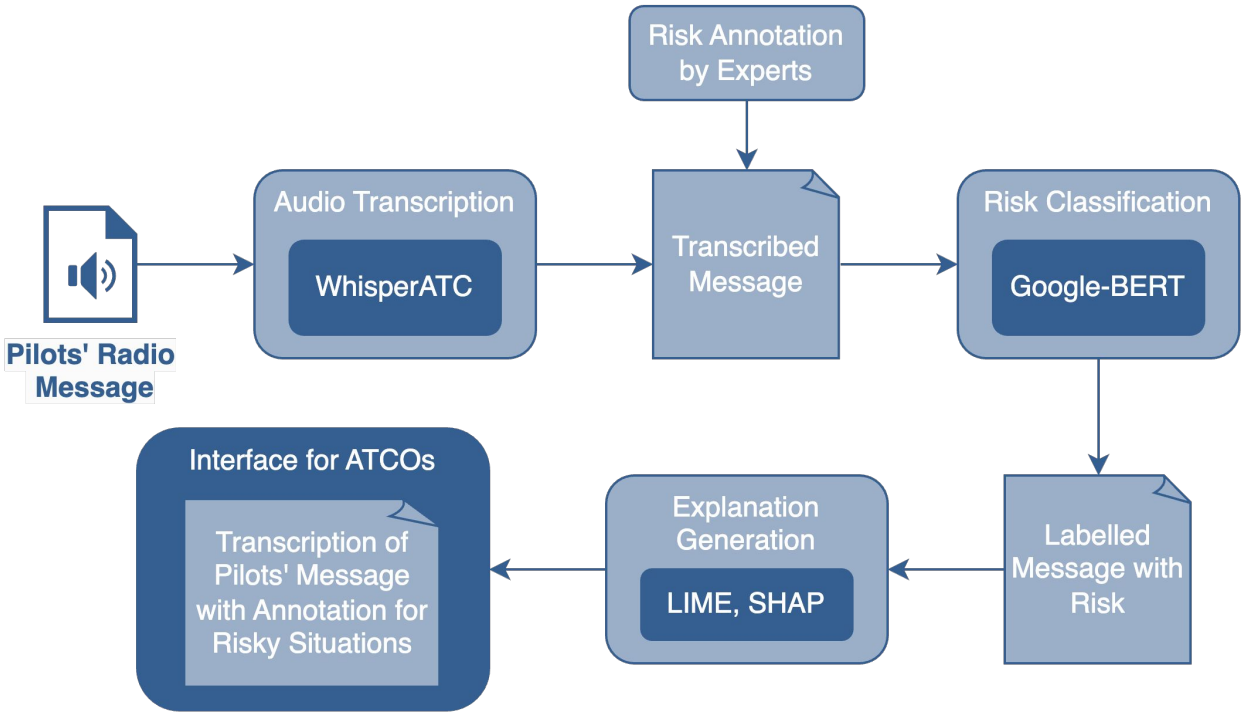
- Offline Active Learning:
  - membership query synthesis,
  - pool-based sampling, and
  - stream-based selective sampling
- Adding vocabulary to YOLO-World

Image: Settles, B. (2009). Active learning literature survey.

Implementation of the AI tools

Multimodal Machine Learning Solution

- **Audio data**
  - Benchmark dataset
    - Text to audio
    - Kokoro library
  - The workflow of audio and text data processing
    - Transcription of radio message,
    - Classification of the transcriptions for high-risk situations
    - Generation of explanations for the classified transcriptions.



https://github.com/hexgrad/kokoro

https://github.com/jlvdoorn/WhisperATC?tab=readme-ov-file

Implementation of the AI tools

Multimodal Machine Learning Solution

TRUSTY

Example of the audio transcription dataset

	danger	event	transcription	errors
2	high	bird strike	**Muret Ground**, **Delta Lima two three five**, **DR400**, Bird strike during climb. Critical Issue. Request immediate return to airdrom.	(**ritorn**, refund), airdrome (**heir drum**, air dome, air roam), immediate (**in media** / emit it / imitate)
3	high	bird strike	Aborting climb. Request immediate return to airdrom.	takeoff (**take cough** / tick off)
8	high	bird strike	Request return to stand Alpha Bravo.	/ **tick off**), stand (**sand**, spend)
9	high	bird hazard	birds.	flock (**floc** / flok), birds (**berds** / burds)
10	high	bird hazard	birds scaring services.	services (**serves us** / surfaces)
11	high	bird hazard	around aircraft.	(berds / **burds**)
27	high	engine failure	thousand feet. Request immediate return to airdrom.	roam)
28	high	engine failure	feet. Request immediate return to airdrom.	gene), issue (I shoe, Is you, **It's you**)
32	high	engine failure	Request immediate return to airdrom.	**feel your** / fair lure)
53	high	low fuel	one zero. Request priority landing.	(**dissent** / decent / disc sent)
61	high	low fuel	Return to airdrom.	(dissent / **decent** / disc sent)
63	high	low fuel	Request immediate descent.	(dissent / decent / **disc sent**)
67	high	runway occupied	go-around.	**glow around** / gore hound)
70	high	runway occupied	hundred feet. Initiate go-around.	descent (dissent / decent / **disc sent**)
76	high	runway occupied	go-around.	around / glow around / **gore hound**)
77	high	fire on runway	on runway.	fire (**fryer** / flier / higher)
78	high	fire on runway	taking-off.	taken off)
79	high	fire on runway	**Muret Ground**, **Juliet Romeo six zero two**, **TB20**, Fire observed on **Runway 30L**. Initiate go-around. Wait for information updates.	**glow around** / gore hound), information (inform nation / **in formation**)
80	high		**Muret Ground**, **Victor Tango seven nine zero**, **DR400**, Holding **Runway 30L** due to intense	intense (in tents / intents), smog (**slog** / smock),

Implementation of the AI tools

TRUSTY

Multimodal Machine Learning Solution

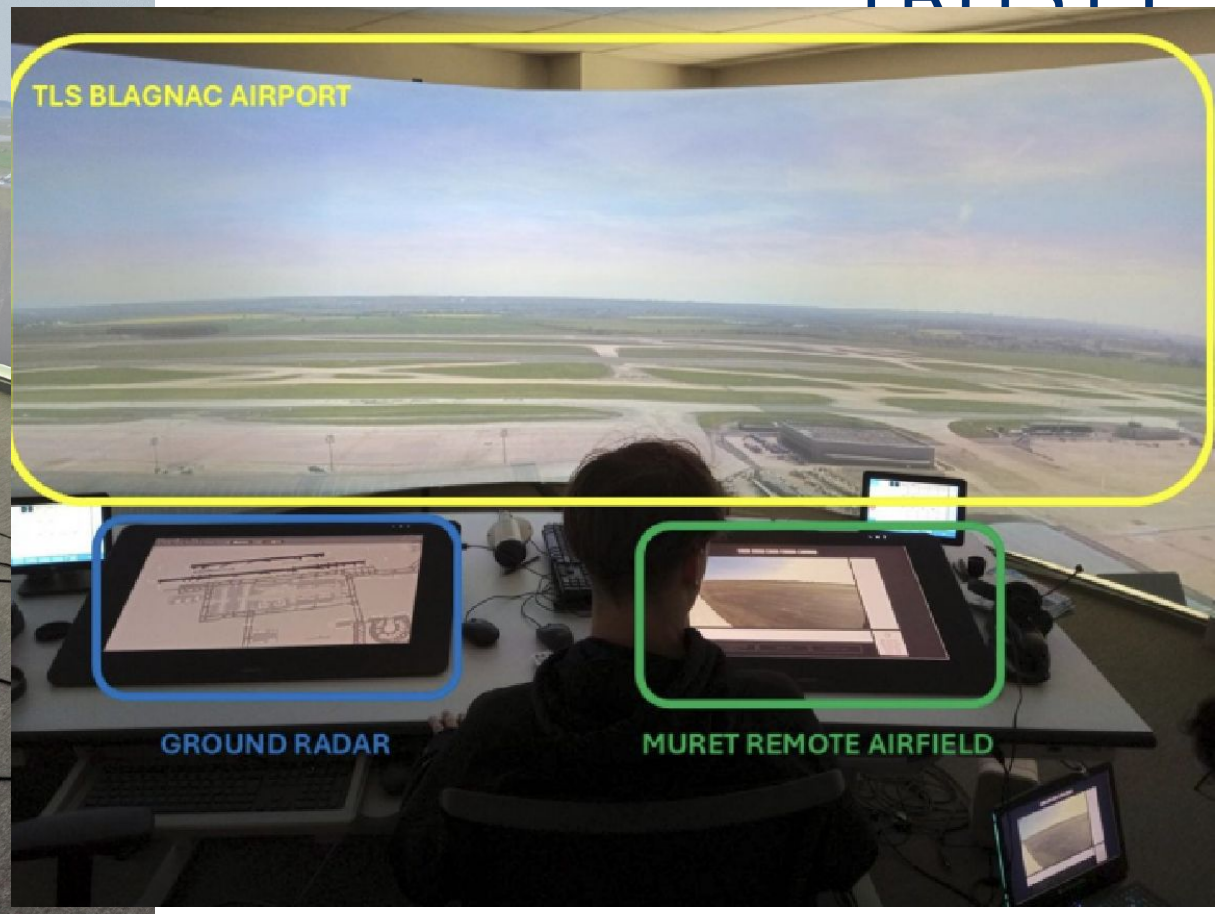
- Input
  - Audio data
- Output
  - Transcript
- Explanation
  - Labelling highlighting the semantic word

Audio Classification and explanation

Risk	Explained Transcription
High	**Text with highlighted words** Muret Ground, Delta Papa three three four, TB20, Holding Runway 30L, wind shear ongoing. Wait for information updates.
Low	**Text with highlighted words** Muret Ground, Victor Zoulou seven four nine, DR400, Request take-off clearance Runway 30L.

Controllers' reaction

Results – Trust, Explainability and Modality



TRUSTY

Combining Variables – Conditions

Video System		**AI Technical Reliability** Treatment		
		90%	60%	No AI
Visualization Treatment	All objects detected are shown	All/90	All/60	No
	All objects are shown with indication of what the object is	All+label/90	All+label/60	
	Only objects that are likely to have a safety implication are shown with explanation of why its being shown	Select+exp/90	Select+exp/60	

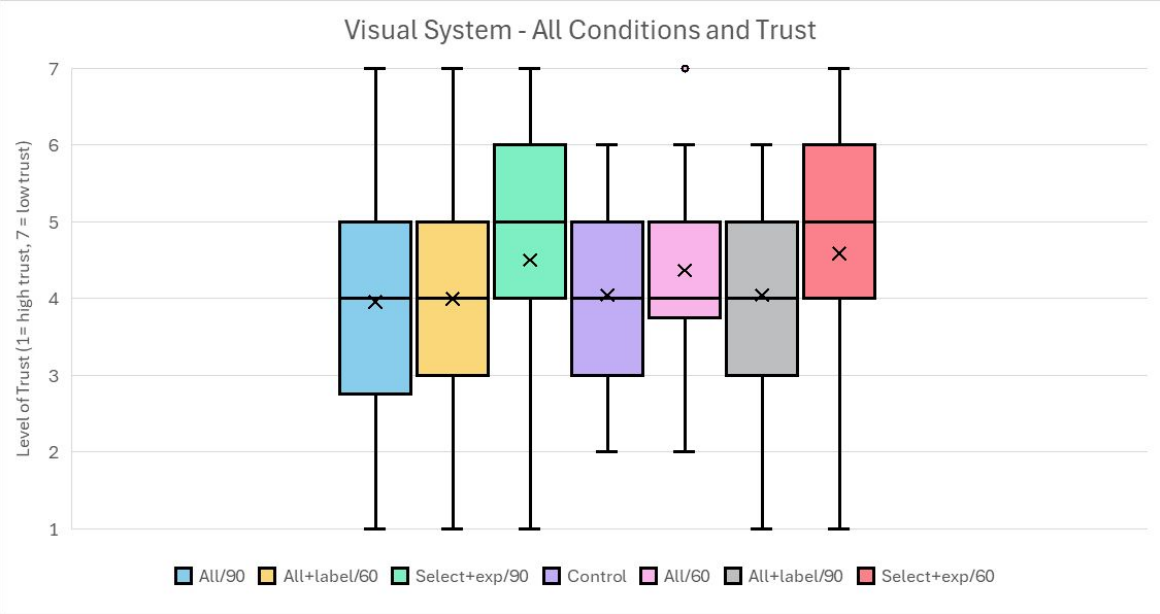
Audio System		**AI Technical Reliability** Treatment		
		90%	60%	No AI
Visualization Treatment "Audio"	Transcription of all calls	All/90	All/60	No
	Transcription of all calls and highlighting of important words in each message	All+label/90	All+label/60	
	Transcription of all calls and highlighting of important words in important messages only	Select+exp/90	Select+exp/60	

- Transparency: What is the AI showing me?
- Explainability: Why is it showing me this?
- Shared mental model: Do I need to know what the AI is showing me?

Results – Trust – All conditions – Video System

- The most ‘explained’ visualization, namely the Select+exp, was the ***least trusted*** consistently.
- This was *regardless of the level of AI reliability*.

Visual Condition	Trust Level
All/90	Most Trust
All+label/60	
Control (No AI)	
All+label/90	
All/60	
Select+exp/90	
Select+exp/60	Least Trust

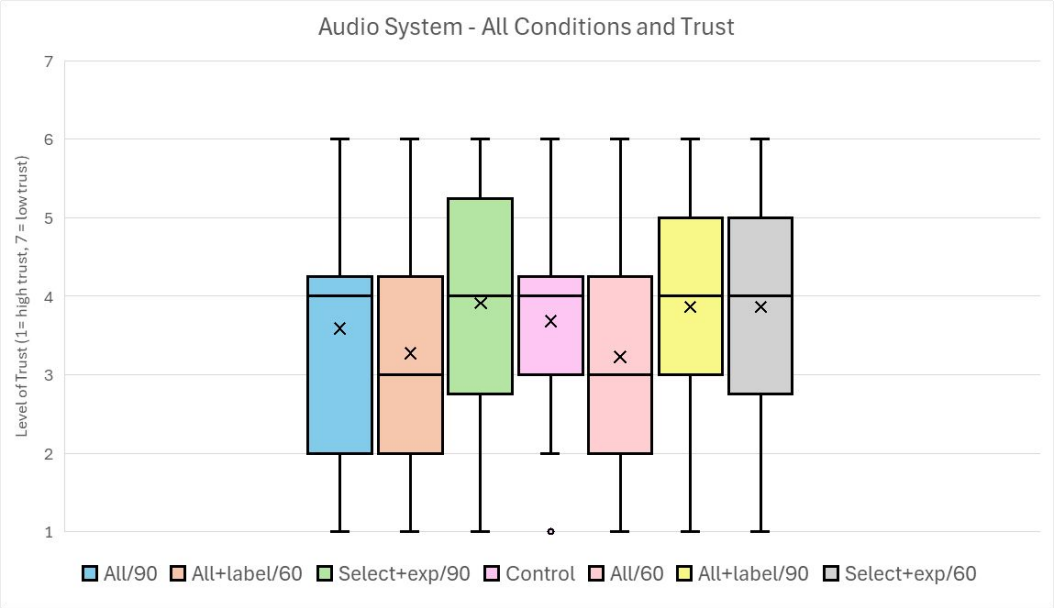


Higher Trust		Lower Trust	Statistic	p
All/90	>	Select+ exp/90	2.428	0.017*
All/90	>	Select+ exp/60	2.686	0.009*
All+ label/60	>	Select+ exp/90	2.014	0.047*
All+ label/60	>	Select+ exp/60	2.273	0.025*
Control(No AI)	>	Select+ exp/90	2.221	0.029*
Control(No AI)	>	Select+ exp/60	2.479	0.015*

Results – Trust – All conditions – Audio System

- Again the most ‘explained’ visualization, namely the Select+exp, was the ***least trusted***.
- The findings show that 60% AI reliability appears to perform more favorably with the participants.

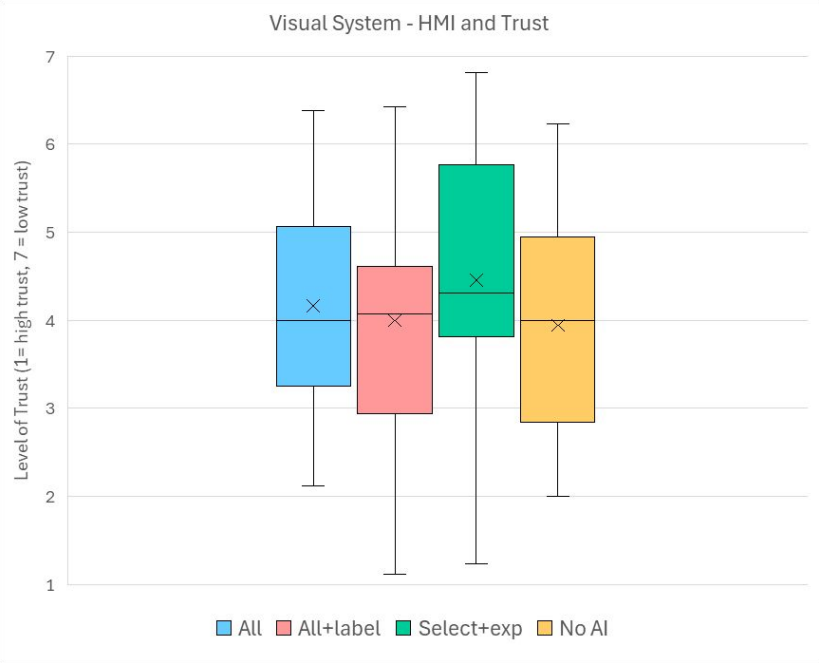
Audio Condition	Trust Level
All/60	Most Trust
All+label/60	
All/90	
Control	
All+label/90	
Select+exp/60	
Select+exp/90	Least Trust

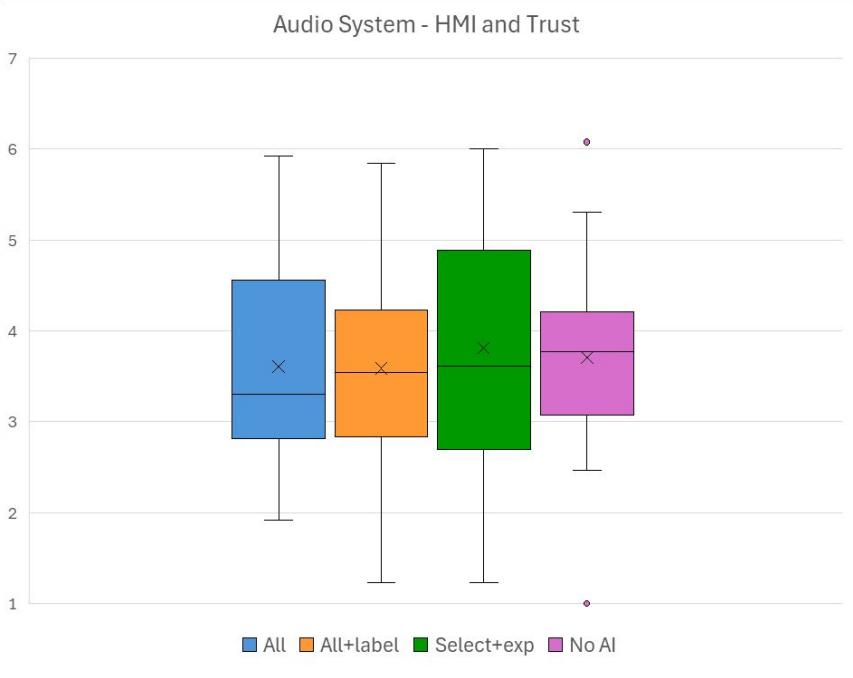


Higher Trust		Lower Trust	Statistic	p
All+label/60	>	**Select+exp/90**	2.3238	0.022*
All+label/60	>	**All+label/90**	2.1172	0.037*
All+label/60	>	**Select+exp/60**	2.4787	0.015*
All/60	>	**Select+exp/90**	2.3754	0.020*
All/60	>	**All+label/90**	2.1689	0.033*
All/60	>	**Select+exp/60**	2.5303	0.013*

Results – Trust – HMI– Both Systems

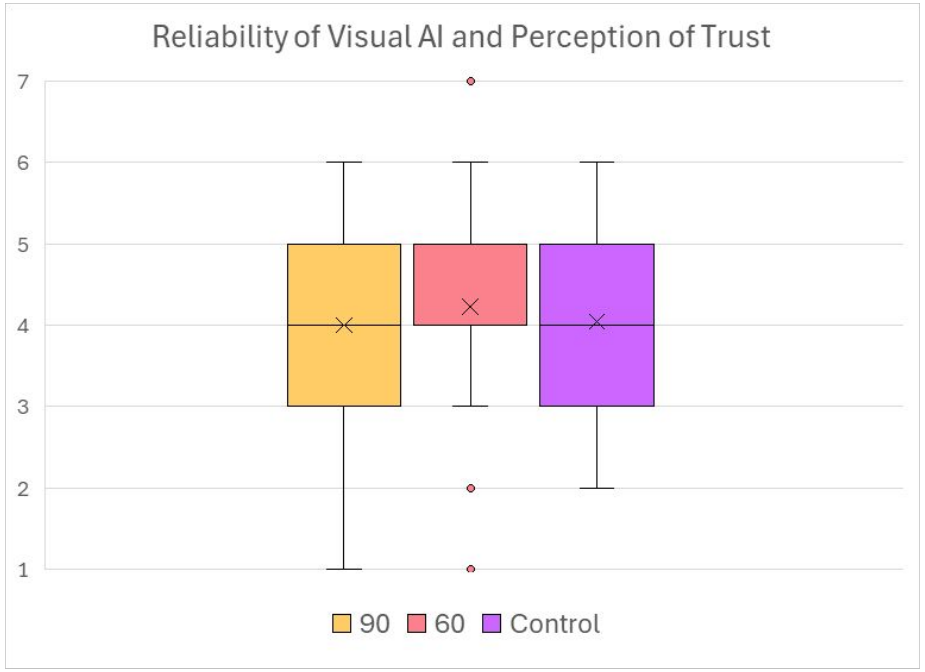
- Trust was statistically significantly higher in All+Label and the control (No AI) compared to the Select+exp HMI, for the **visual system**.
- There was a non-significant result for difference in trust ratings across the four HMI visualizations for the **audio system**.

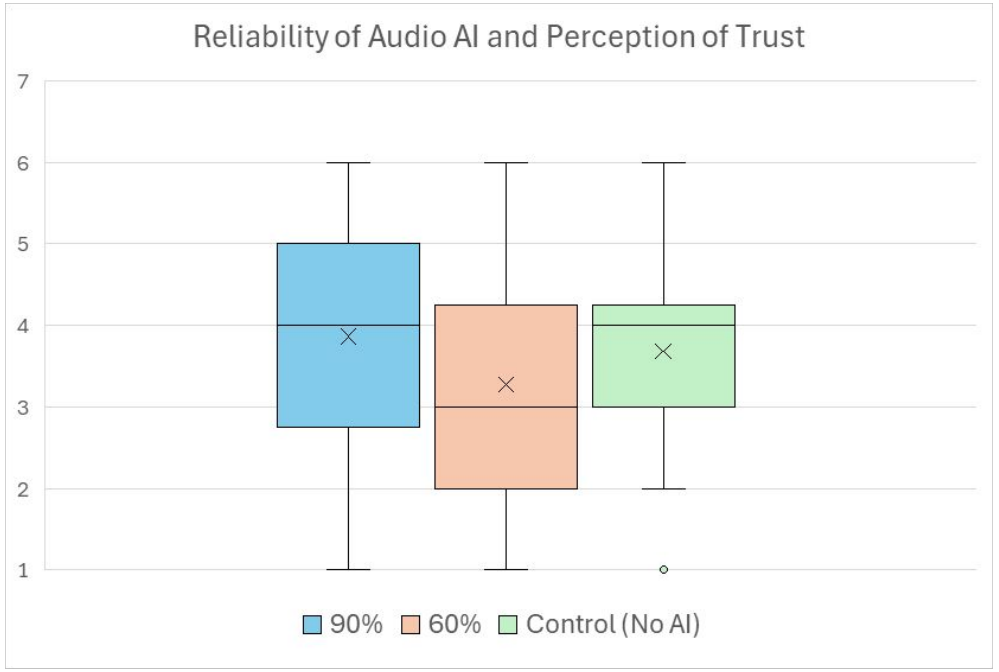




Results – Trust – Reliability – Both Systems

- There was a non-significant result for difference in trust ratings across the 3 reliability conditions for the **visual system**.
- Trust was significantly higher in those conditions which displayed 60% in reliability in comparison with those in the 90% or Control (No AI) condition, for the **audio system**.





TRUSTY

“Regarding the AI, I found it reassuring that it made a mistake”

“They (an ATCO) might make mistakes, but they’re trained to correct themselves.”

Results – Trust – Modality – Video vs Audio Systems

Participants showed generally **more trust in the audio system** than the visual system across all 7 conditions.

Higher Trust		Lower Trust	Statistic	p
Audio: All+label/60%	>	**Visual: All+label/60%**	0.00	0.01*
Audio: All/60%	>	**Visual: All/60%**	0.00	0.005*
Audio: Select+exp/60%	>	**Visual: Select+exp/60%**	0.00	0.007*

Participants reported a **greater shared mental model in the Audio system** versus the Visual system for some conditions.

- "I know what will happen the next time I use the AI system because I understand how it behaves."
- "I understand how the AI system will assist me with the decisions I have to make."

Greater Perceived Shared Mental Model	Lesser Perceived Shared Mental Model		Statistic	p
Audio All+label/60	Visual All+label/60	Wilcoxon W	68.0	0.019*
Audio Select+exp/60	Visual Select+exp/60	Wilcoxon W	0.00	<.001*

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THANK YOU FOR YOUR ATTENTION

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CODA

CODA: COntroller adaptive Digital Assistant
Final results

Stefano Bonelli

deepblue

AI based innovation in ATM: improving Efficiency, Trust and Safety

SESAR Innovation Days 2025

SUPPORTED BY sesar JOINT UNDERTAKING

Co-funded by the European Union

Project Overview

CODA: COntroller adaptive Digital Assistant

- **SESAR Exploratory Research project** (TRL2)
- September 2023 -> February 2026
- **Technical work done:** final results available

- **The rationale for the system:** to anticipate possible problems related to controllers' mental states (e.g. workload peak) and activate AI based supporting tools so to mitigate/avoid issues.
- **Expected impact:** efficiency, capacity, and safety, maximizing Human-AI teaming.

With the contribution of

This project has received funding from the SESAR Joint Undertaking under the European Union's Horizon Europe research and innovation programme under grant agreement No 101114765

The CODA Solution

Adaptive System to improve Human AI Teaming

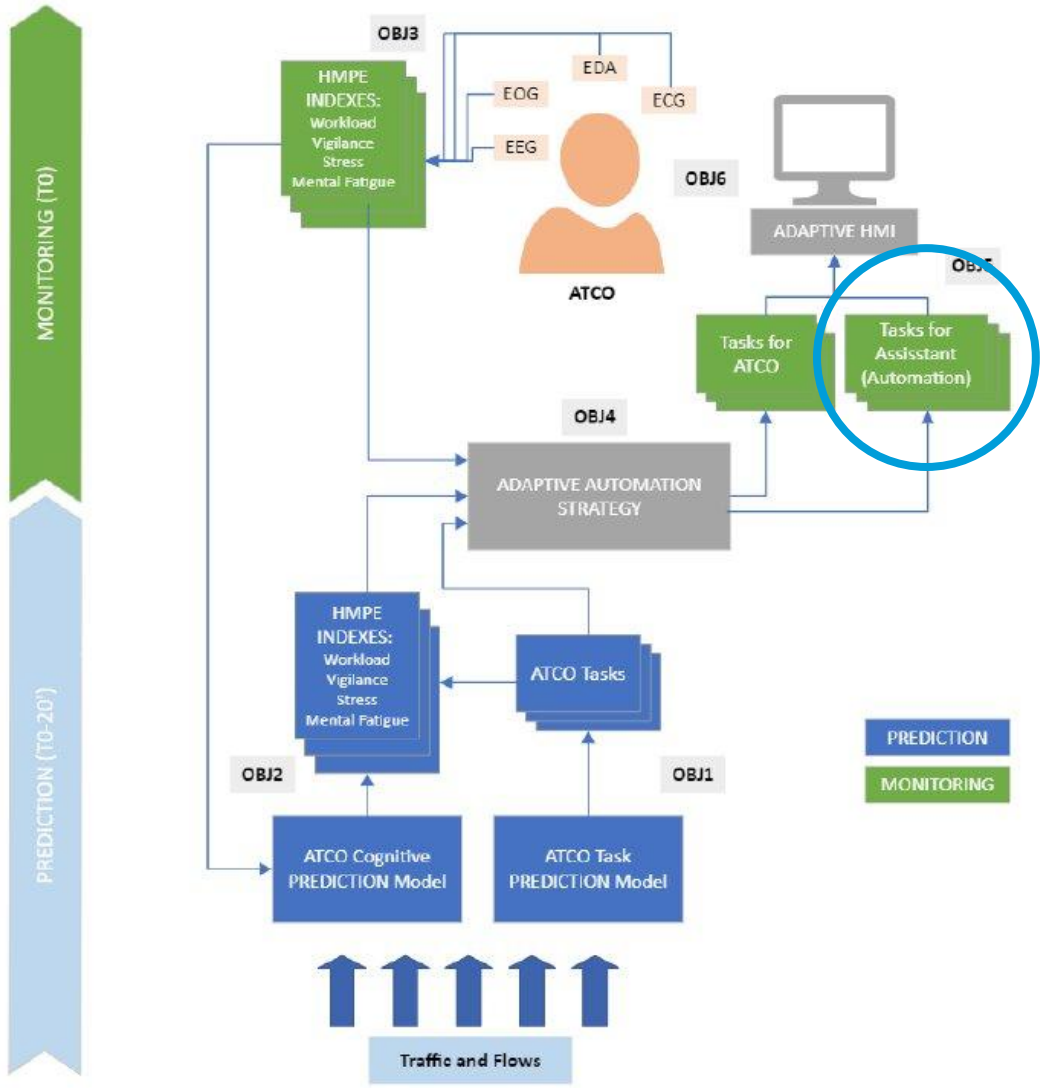
HOW DOES CODA WORKS?

CODA is a predictive adaptive system:

It proposes the **delegation of certain tasks/flights to the AI**

Considering:

- The **current and predicted traffic**
- The **current and upcoming control tasks**
- The curr**ent and predicted controller's mental state** (workload, fatigue, stress, and vigilance)



En-route use case, multiple other applications

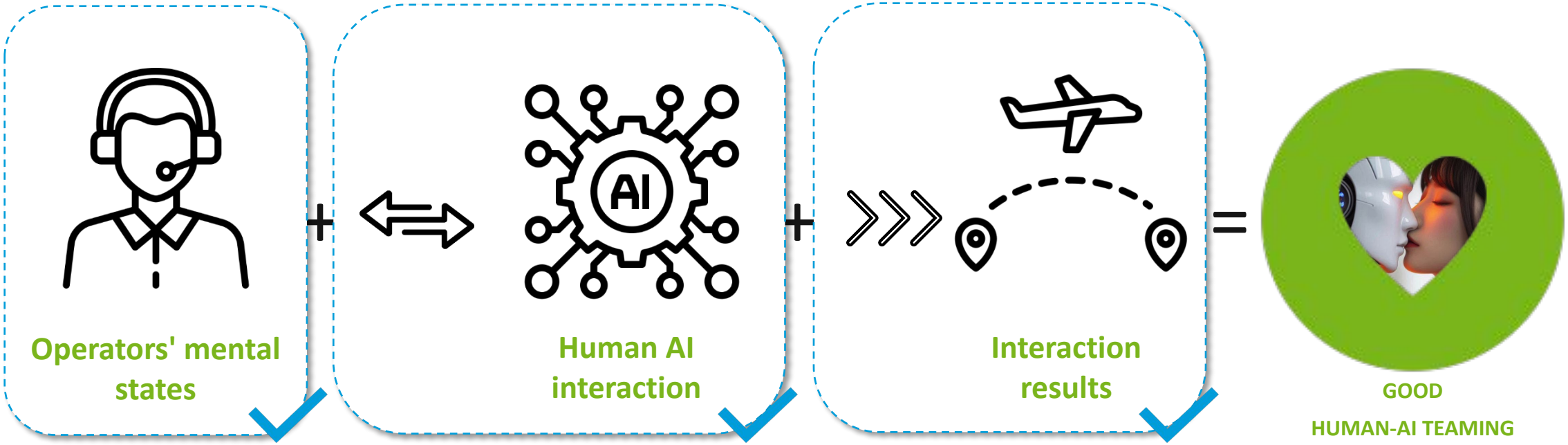
“ONE TOOL TO RULE THEM ALL”

It has to be *emphasised* that the CODA system is not a tool per se. It is a **technological enabler, to be integrated into ATM systems** (not limited to en-route CWPs), providing adaptation capabilities.

The AI tools/Digital assistants that are expected to be activated by the adaptation strategy are out of the scope of the project.

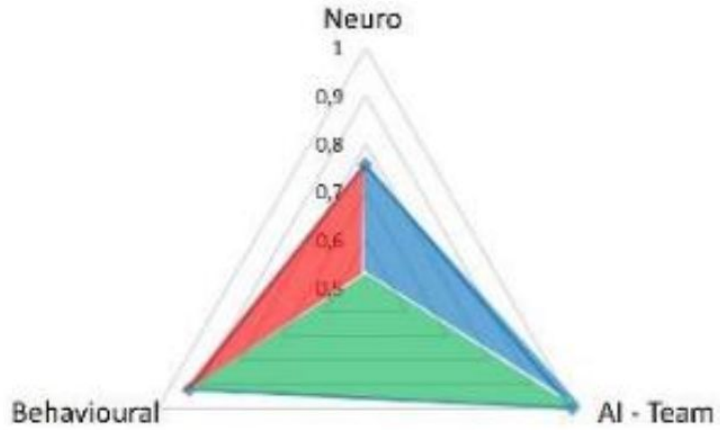
CODA Approach to Human AI Teaming

“A” definition for Human – AI Teaming



“A” way to measure teaming

Human Machine Performance Envelope (HMPE)

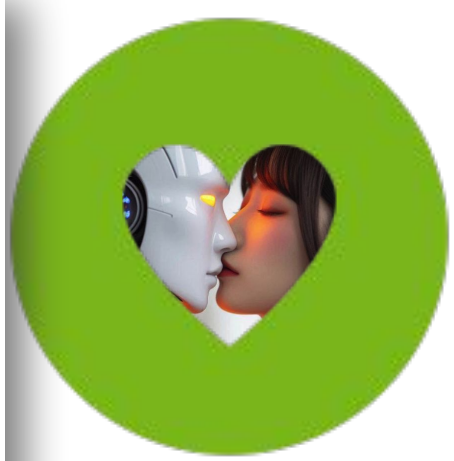


Area Triangle #1 = 1/2 * AI-Team * Behavioural * sin(120°)

Area Triangle #2 = 1/2 * Behavioural * Neuro * sin(120°)

Area Triangle #3 = 1/2 * Neuro * Behavioural * sin(120°)

Area = Area Triangle #1 + Area Triangle #2 + Area Triangle #3



GOOD

HUMAN-AI TEAMING

Human Machine Performance Envelope INDEX

HUMAN-AI TEAMING

ASSESSMENT

VALIDATION

“A” way to manage teaming

ADAPTATION STRATEGY

Sharing the work with an AI may mean:

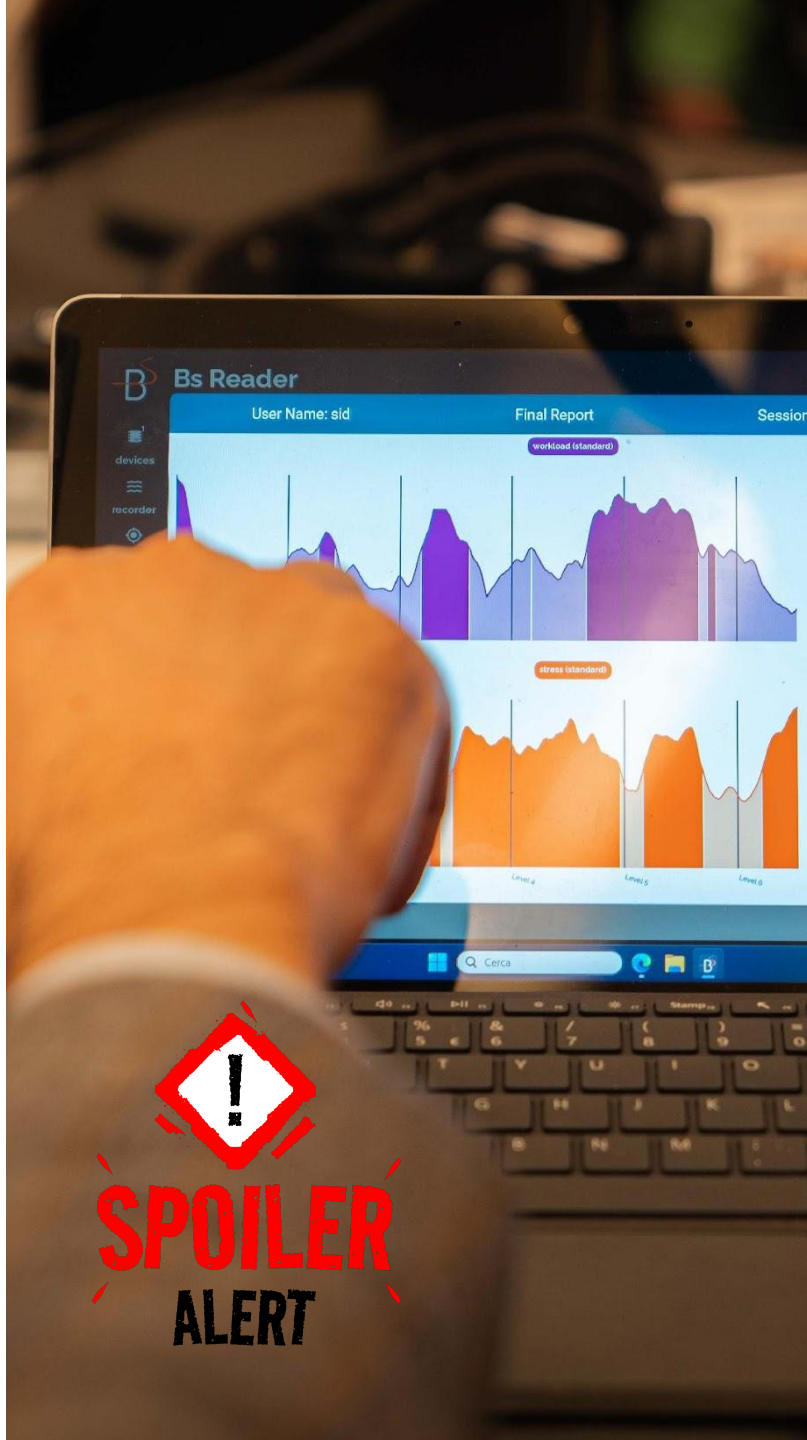
- Distribute specific **tasks** (e.g. assuming flights)
- Assign specific **flights** (e.g. an overflying a/c with no interaction with the traffic)
- Receive support for specific **cognitive functions** (e.g. information analysis to lower workload in a busy sector)

In order to support the ATCO in the best way possible, the adaptation strategy needs to take into consideration operational, safety, ethics and liability aspects.

→ **Generic guidelines**

Results per system module

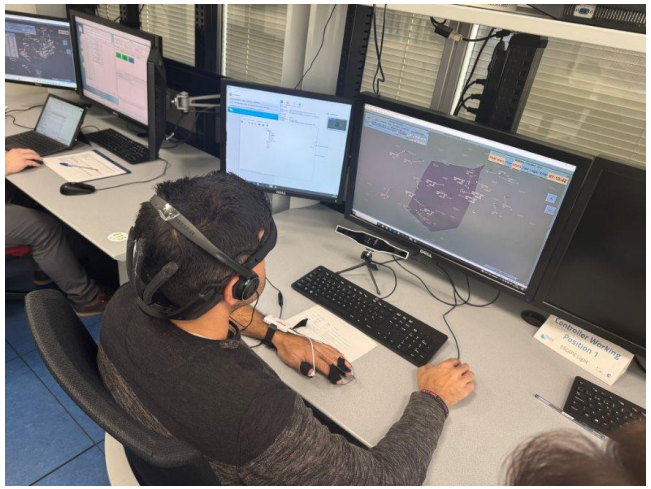
- **Tasks prediction:** probabilistic, different approaches depending on the tasks type
- **Mental states prediction:** workload and fatigue predictions aligned reasonably well with expectations, stress and vigilance predictions were less accurate and more static.
- **Mental state real time monitoring:** all states reliably assessed with EEG
- **Adaptation strategy:** feasibility of prototyping a simple, flight based one. Guidelines for a more comprehensive one provided.
- **HMI**: modular HMI with basic view + detailed one.



CODA system validation

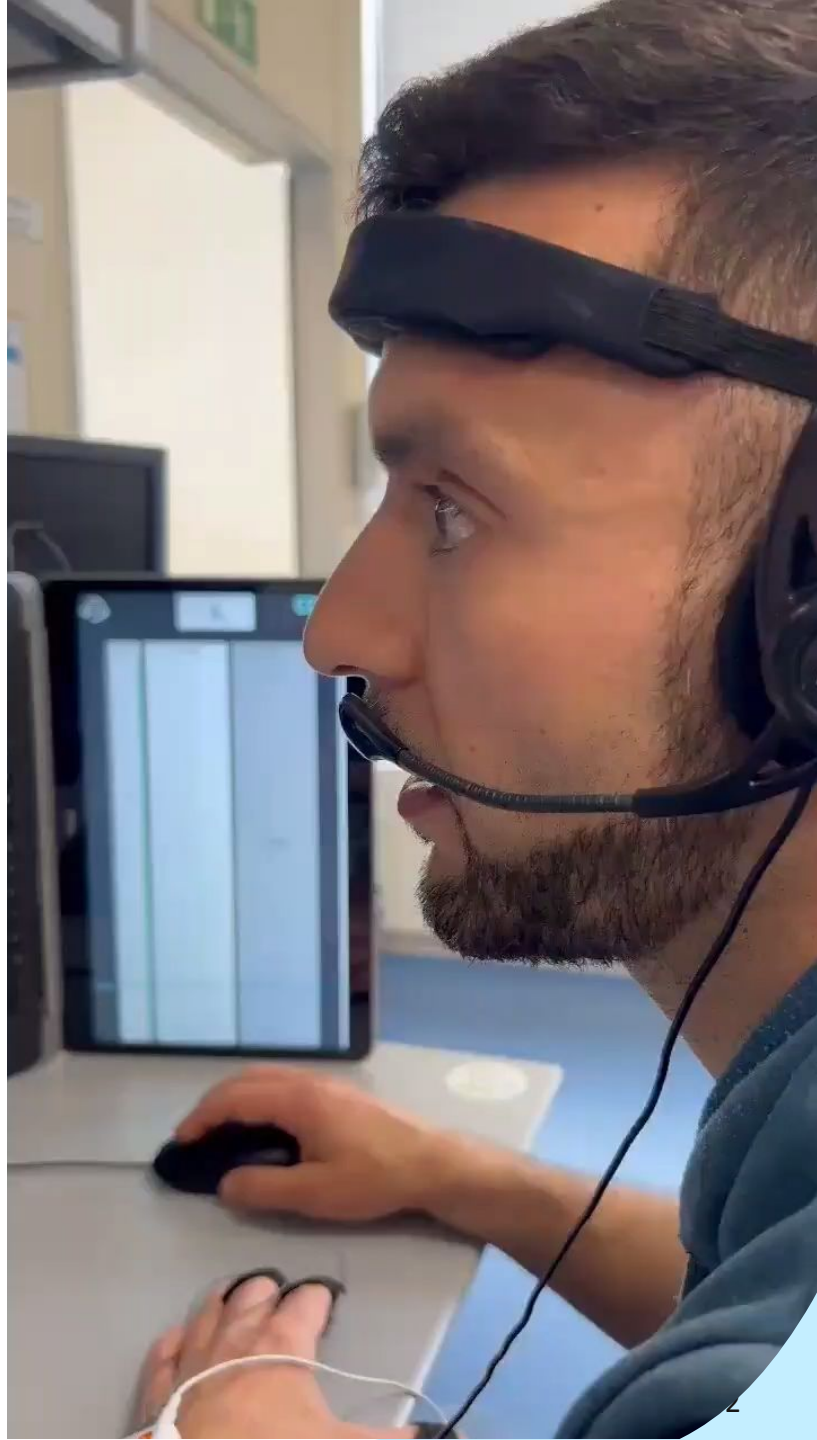
System final validation

Human in the Loop simulation



- **When:** 17–21 March 2025
- **Where:** CRIDA premises at Universidad Politécnica de Madrid
- **Who:** 4 ATCOs (IFATCA)
- **Objective:** Validate CODA system

- Real-time ops with ATCO+CODA system + AI Digital assistant
- Realistic CWP and traffic (ESCAPE platform)
- Pseudopilots (voice communication)
- Yellow circle marked AI flights



The CODA system HMI

THE CODA PROTOTYPE

Due to technical constraints, we focused our prototype development of **flights allocation** between ATCO and AI.

We set different level of autonomy:

- **Low:** ATCO need to approve CODA proposals for AI managed flights
- **High:** Selected Flights are assigned automatically to AI, the ATCO can regain control

→ **HMI used in the final HITL simulation**

Input

From UPM

- Task load
- Predicted task load

From BrainSigns

- Mental state

From CRIDA

- Predicted Mental state
- Traffic
- Predicted traffic
- Real traffic

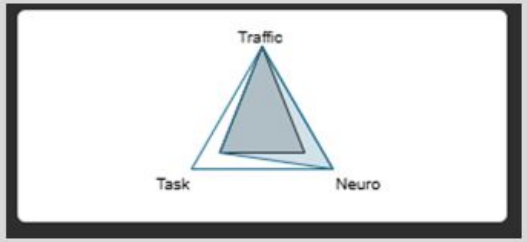
API

LSL

Java Archive & csv files

CODA

Determine whether Coda automation is needed, and display the input.



Transfer the information to the interface

Real-time traffic is displayed on the interface

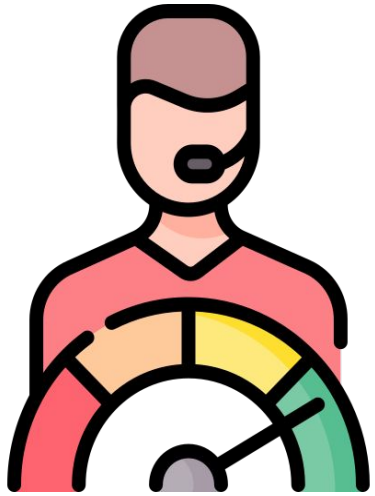
High level results

TWO MAIN QUESTIONS

What's the impact on ATCOs and on operational aspects?

Is HMPE a valid method to measure Human AI teaming?

Impact (Human Performance)



Human Performance

- A generally positive impact on **teaming**
- Improved **vigilance and situation awareness,** reduced **stress and fatigue**
- Not significant change in mental **workload** (due to learnability curve plus a need for monitoring AI-managed aircraft)
- Relatively clear **responsibilities and tasks** as well as new procedures for ATCOs
- CODA's **allocation strategy** was reported to be logical and efficient
- The **HMI** was relatively supportive but there's still room for improvements

Impact (Other KPAs)

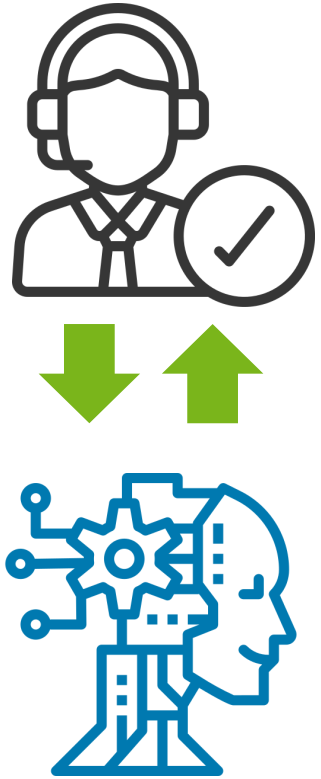
- CODA maintained **safety** in normal conditions and measurably reduced conflicts during peak traffic
- CODA delivered slight improvements in **operational efficiency**
- No measurable improvement in **cost efficiency** was observed
- No measurable impact on en-route throughput was observed, CODA will likely enable an increase in **capacity**

OTHER KPAs

Human Machine Performance Envelope index assessment

➡️ The **HMPE framework** proved to be a strong indicator of controller-AI collaboration

- Aligned with questionnaires and interviews
- Considered reasonable by ATCOs



Human AI teaming assessment

Conclusions

The results identified three key factors influencing **human–AI teaming effectiveness:**

- accurate trust calibration,
- context-aware adaptive behavior, and
- Efficient explainability.

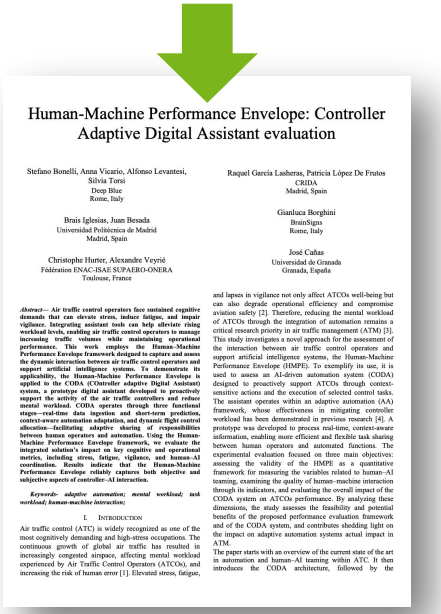
Beyond these empirical results, the study highlights the potential of the HMPE as a **diagnostic and design tool** for human–AI joint systems. By providing a quantitative view of cognitive states and team dynamics, the HMPE offers a means to monitor and adapt human–machine interaction in real time.

This could inspire AI based, **adaptive interface management approaches in ATC**, enabling automation to dynamically adjust its level of assistance according to operators' personal and contextual-driven cognitive boundaries rather than fixed operational thresholds.

Main outcomes you may be interested into:

Detailed description + Final test/validation results for:

- **Tasks prediction approach**
- **Mental states prediction approach**
- **Adaptation strategy**
- **Human Machine Performance Envelope**
- **Project final results**



Human-Machine Performance Envelope: Controller Adaptive Digital Assistant evaluation

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***Abstract*— Air traffic control operators face sustained cognitive demands that can elevate stress, induce fatigue, and impair vigilance. Integrating assistant tools can help alleviate rising workload levels, enabling air traffic control operators to manage increasing traffic volumes while maintaining operational performance. This work employs the Human–Machine Performance Envelope framework designed to capture and assess the dynamic interaction between air traffic control operators and support artificial intelligence systems. To demonstrate its applicability, the Human-Machine Performance Envelope is applied to the CODA (Controller adaptive Digital Assistant) system, a prototype digital assistant developed to proactively support the activity of the air traffic controllers and reduce mental workload. CODA operates through three functional stages—real-time data ingestion and short-term prediction, context-aware automation adaptation, and dynamic flight control allocation—facilitating adaptive sharing of responsibilities between human operators and automation. Using the Human-Machine Performance Envelope framework, we evaluate the integrated solution's impact on key cognitive and operational metrics, including stress, fatigue, vigilance, and human–AI coordination. Results indicate that the Human-Machine Performance Envelope reliably captures both objective and subjective aspects of controller–AI interaction.**

Keywords- adaptive automation; mental workload; task workload; human-machine interaction;

I. INTRODUCTION

Air traffic control (ATC) is widely recognized as one of the most cognitively demanding and high-stress occupations. The continuous growth of global air traffic has resulted in increasingly congested airspace, affecting mental workload experienced by Air Traffic Control Operators (ATCOs), and increasing the risk of human error [1]. Elevated stress, fatigue, and lapses in vigilance not only affect ATCOs well-being but can also degrade operational efficiency and compromise aviation safety [2]. Therefore, reducing the mental workload of ATCOs through the integration of automation remains a critical research priority in air traffic management (ATM) [3]. This study investigates a novel approach for the assessment of the interaction between air traffic control operators and support artificial intelligence systems, the Human-Machine Performance Envelope (HMPE). To exemplify its use, it is used to assess an AI-driven automation system (CODA) designed to proactively support ATCOs through context-sensitive actions and the execution of selected control tasks. The assistant operates within an adaptive automation (AA) framework, whose effectiveness in mitigating controller workload has been demonstrated in previous research [4]. A prototype was developed to process real-time, context-aware information, enabling more efficient and flexible task sharing between human operators and automated functions. The experimental evaluation focused on three main objectives: assessing the validity of the HMPE as a quantitative framework for measuring the variables related to human–AI teaming, examining the quality of human–machine interaction through its indicators, and evaluating the overall impact of the CODA system on ATCOs performance. By analyzing these dimensions, the study assesses the feasibility and potential benefits of the proposed performance evaluation framework and of the CODA system, and contributes shedding light on the impact on adaptive automation systems actual impact in ATM.

The paper starts with an overview of the current state of the art in automation and human–AI teaming within ATC. It then introduces the CODA architecture, followed by the

ALL AVAILABLE ON OUR WEBSITE

CODA

THANKS!

Web page:

http://coda-sesar.eu

Linkedin:

https://www.linkedin.com/company/coda-atc

Youtube:

https://www.youtube.com/@CODASESAR

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ASTRA

AI-Driven Complexity Prediction and Resolution for Flow Managers

Jason Gauci
Project Coordinator

Final Dissemination Event
Bled, Slovenia, 5 December 2025

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ASTRA

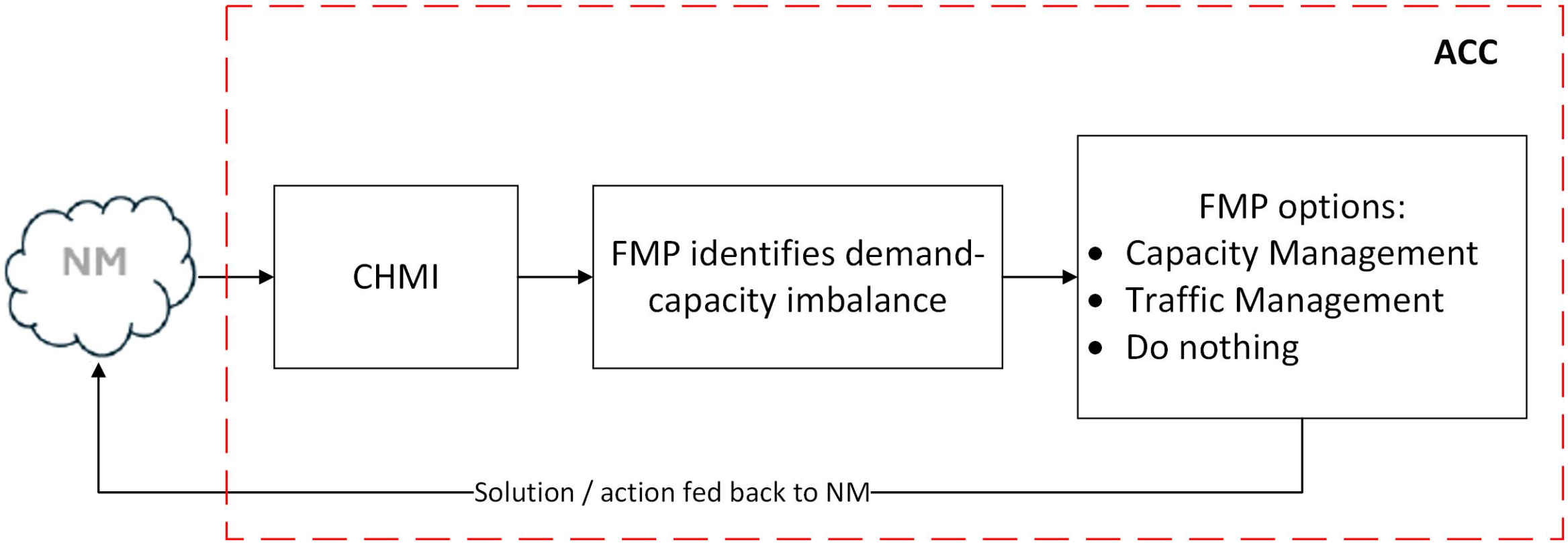
Operational use case

ASTRA Background

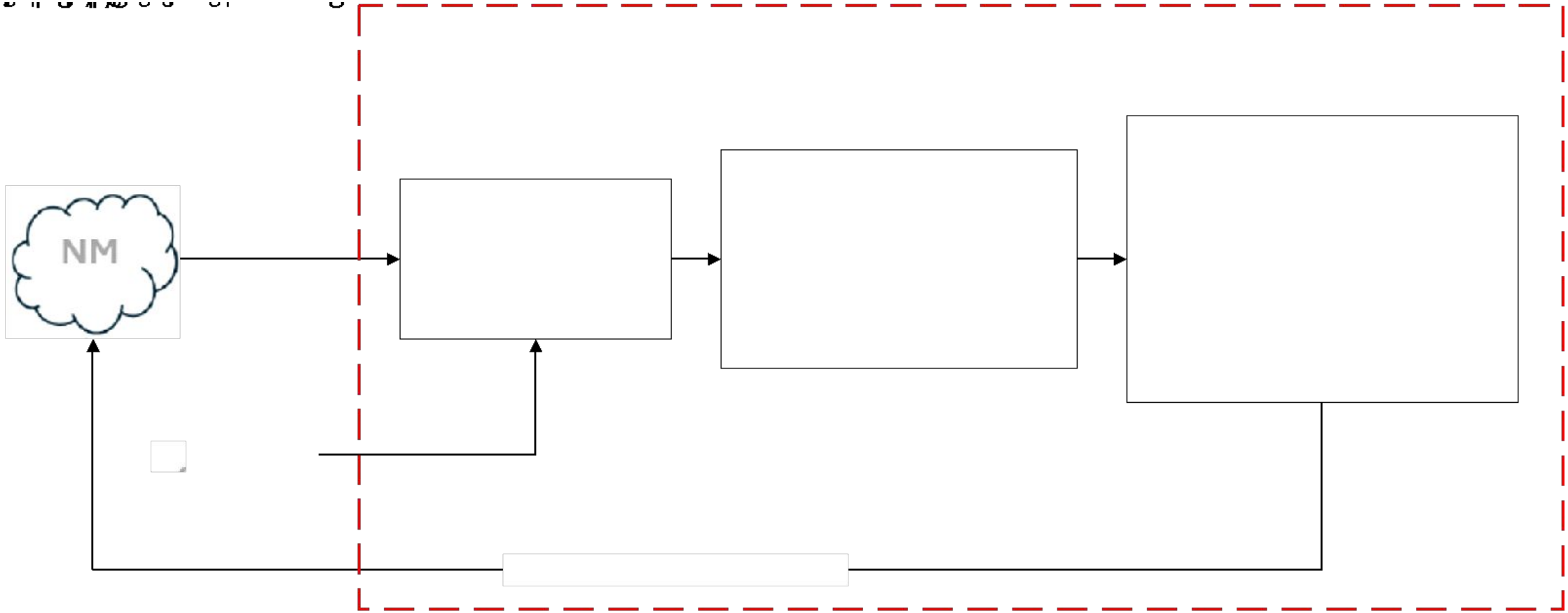
- Although DCB measures are taken during the strategic and pre-tactical phases of flight, imbalances still occur in flight
- These are more likely to cause areas of high air traffic complexity (aka hotspots) that have to be handled tactically by ATCOs
- A hotspot can also occur in a sector that is operating within its declared capacity

Can we predict and resolve hotspots in en-route airspace up to an hour in advance?

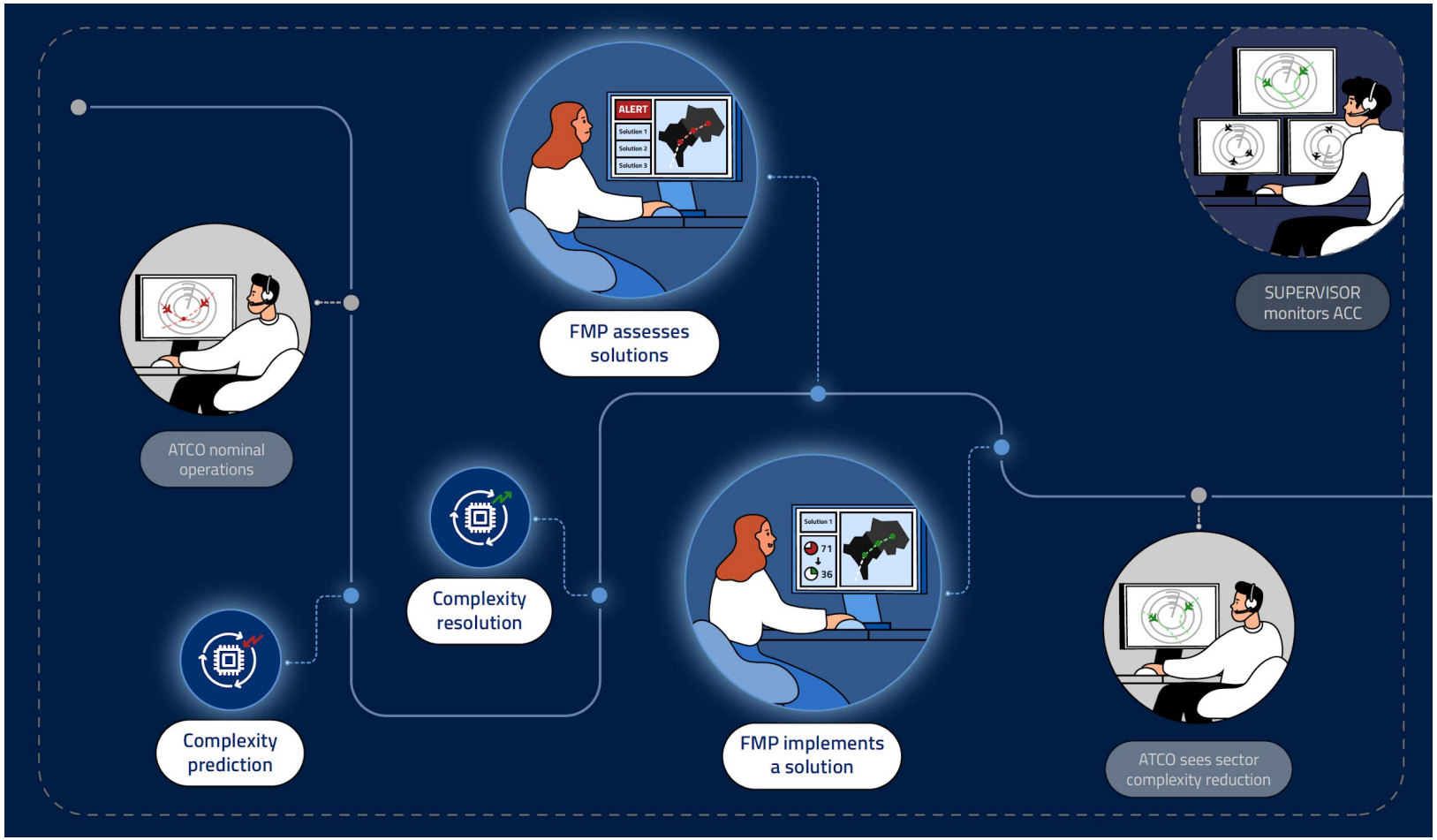
ASTRA Current local ATFCM architecture



ASTRA Local ATFCM architecture with ASTRA



ASTRA Operational concept



ATCO workload

En-route capacity

Fuel efficiency

Safety

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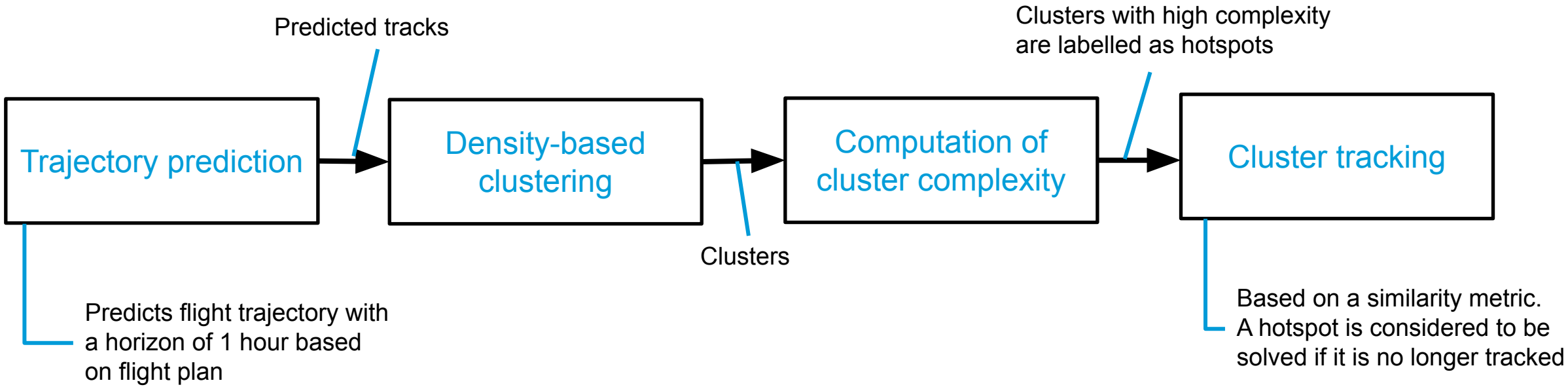
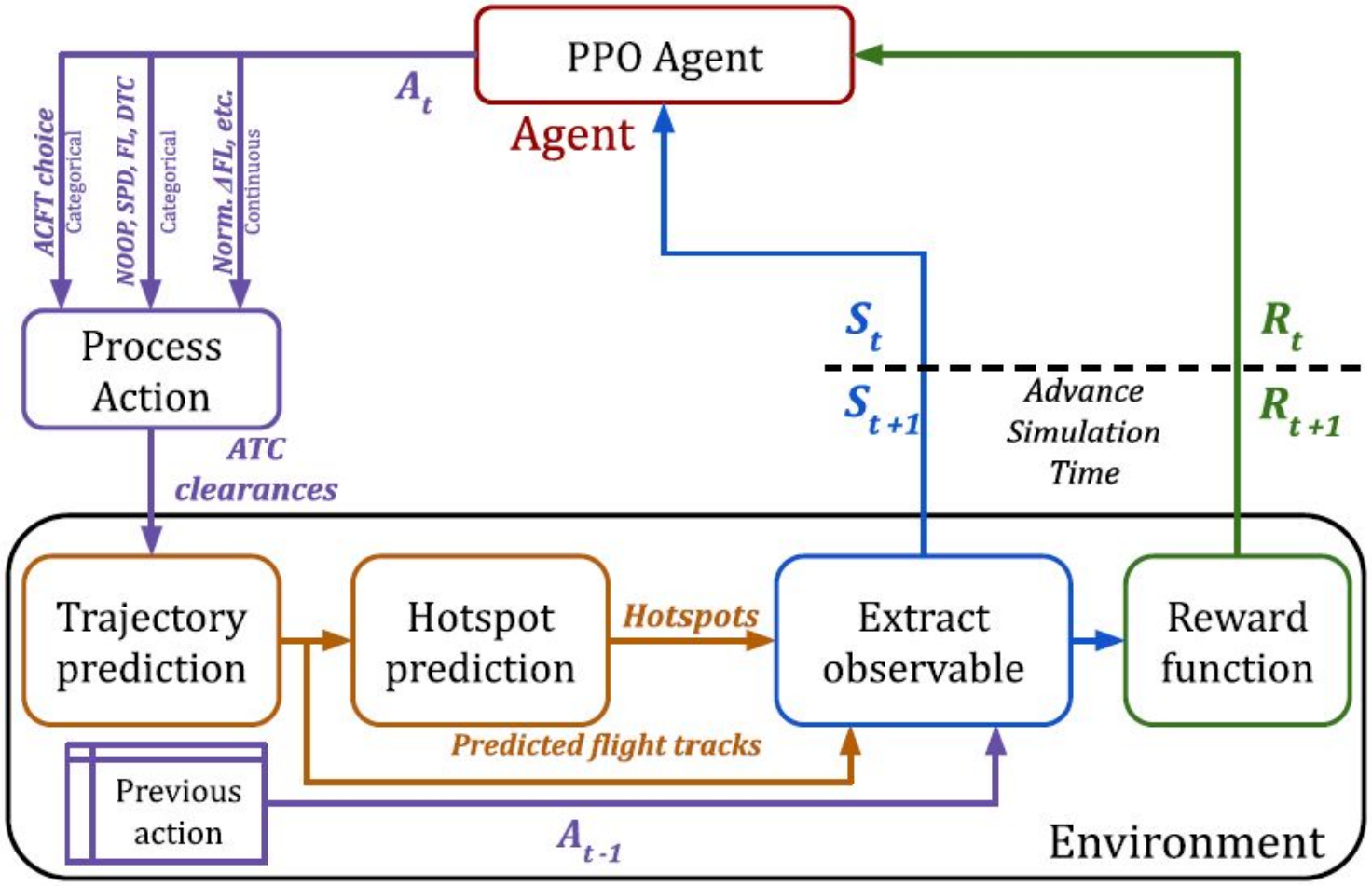
ASTRA

Prediction & resolution

ASTRA Hotspot prediction



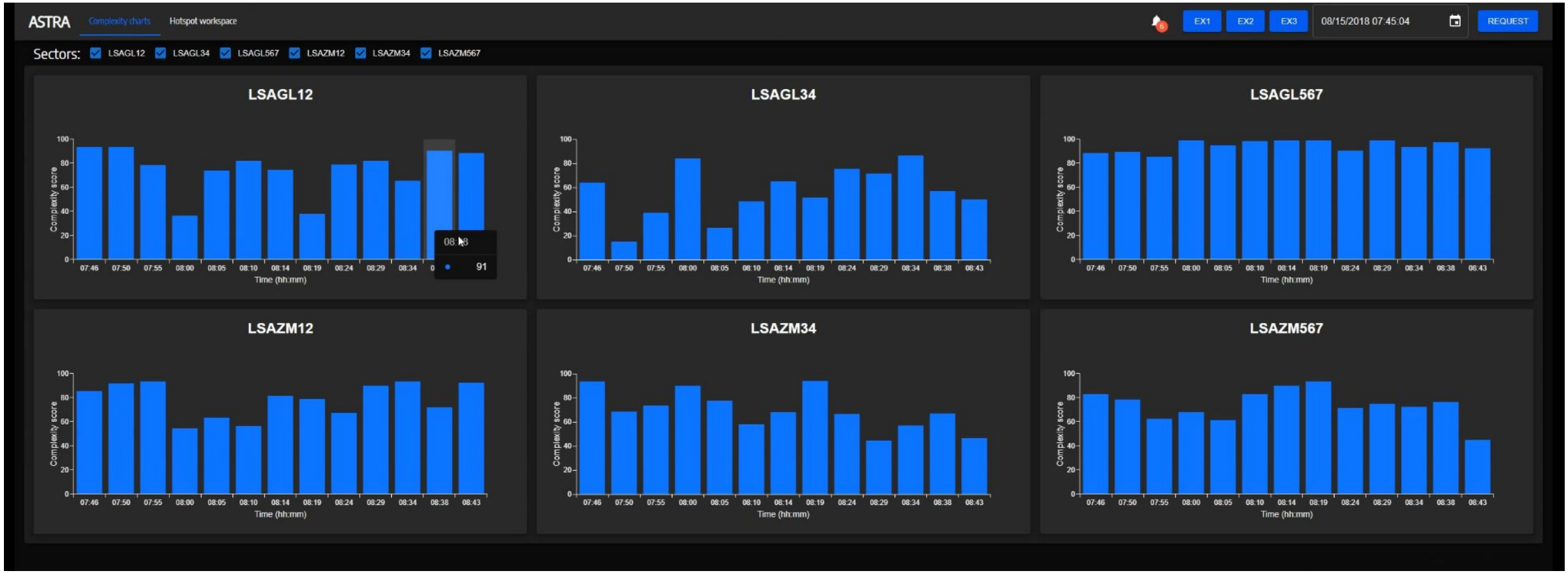
ASTRA Hotspot resolution



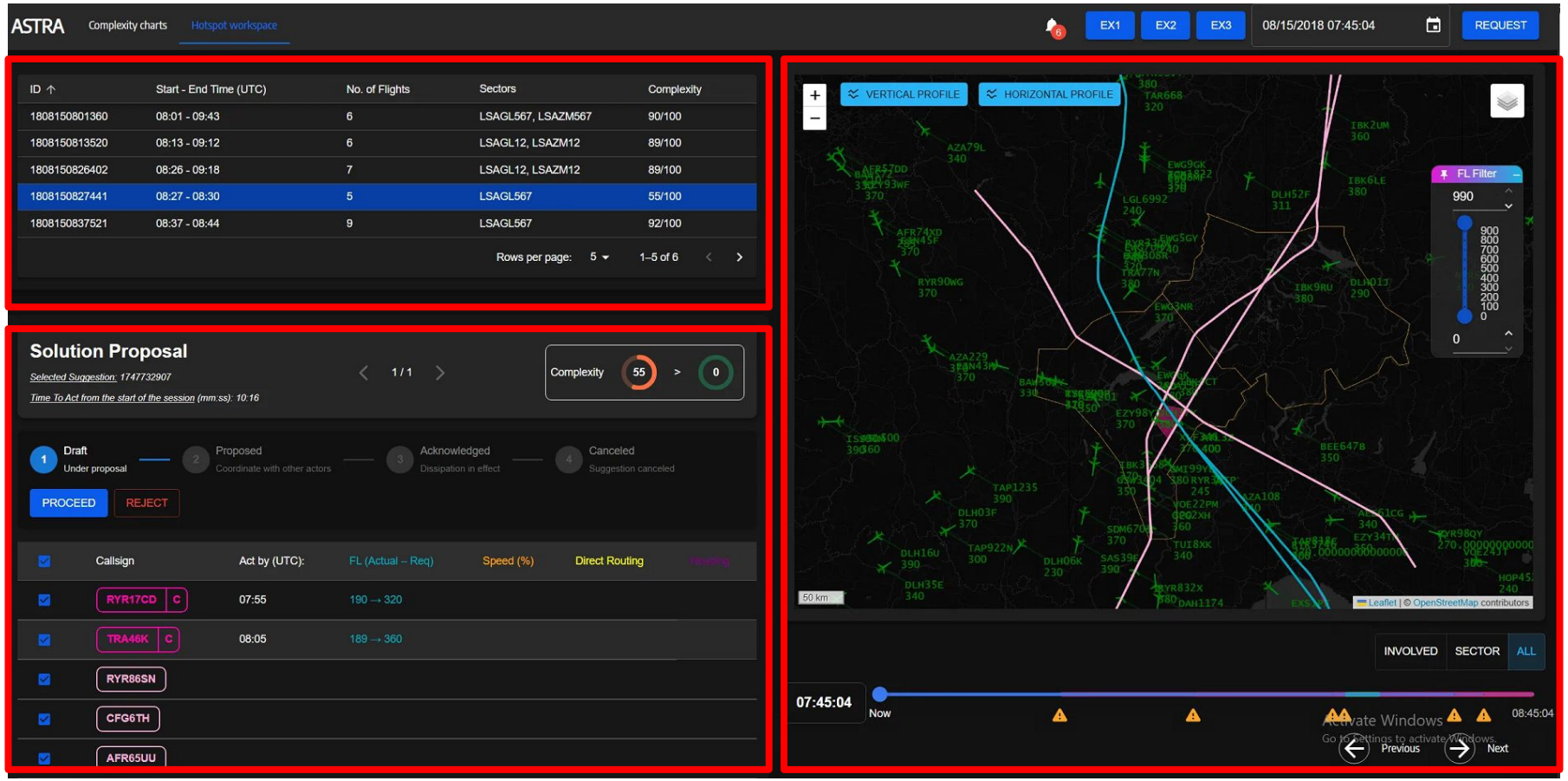
ASTRA

Transparency & interpretability

ASTRA HMI – Complexity charts



ASTRA HMI – Hotspot workspace



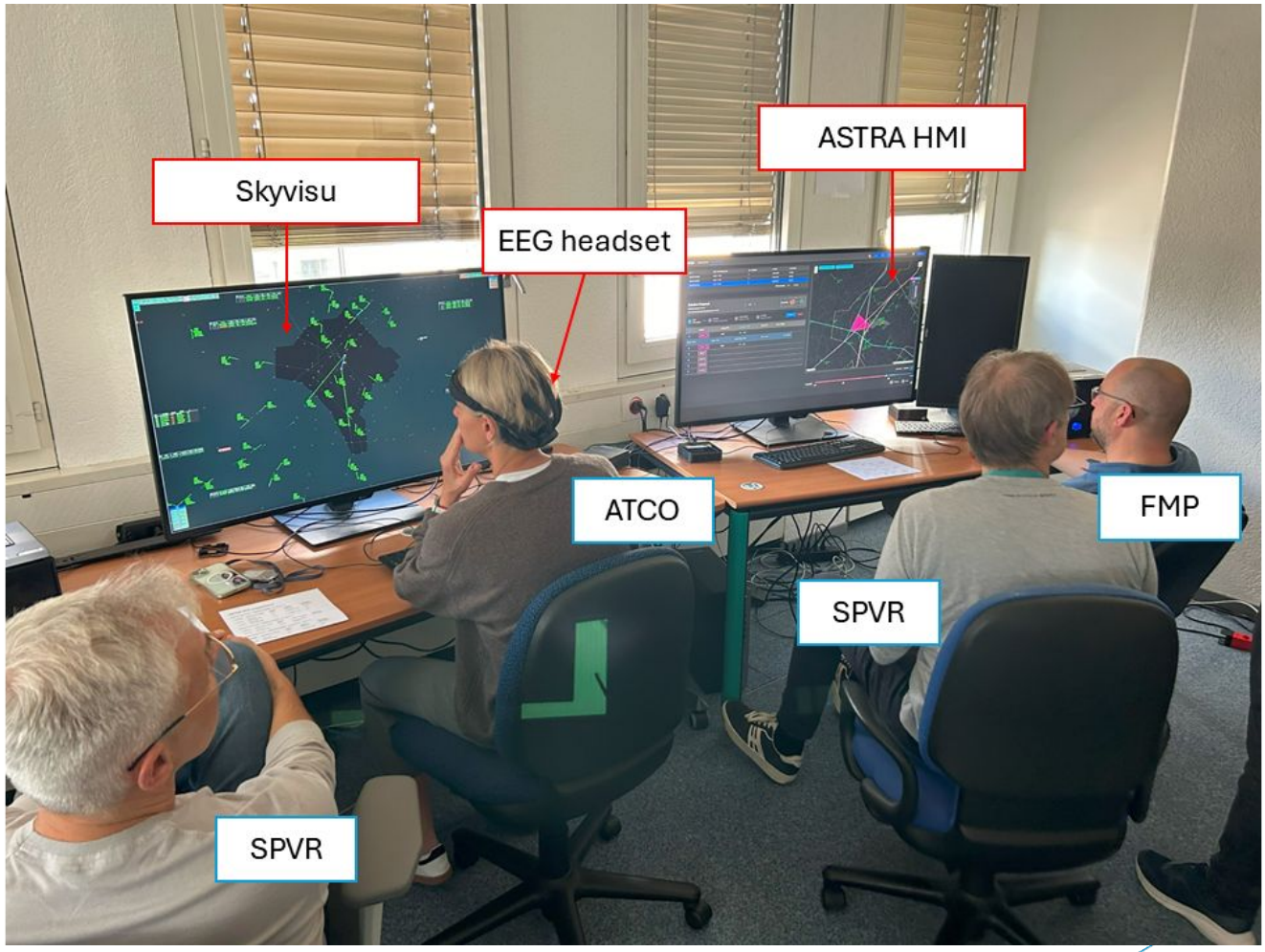
ASTRA HMI – Hotspot workspace

ASTRA

Selected findings

ASTRA Human-in-the-loop RTS

- 26-28 May 2025 (Skysoft-ATM)
- 10 participants (3 FMPs, 3 ATCOs, 4 ATCO supervisors)
- 3 use cases based in Geneva ACC
- One hotspot per use case
- Each use case was repeated without and with ASTRA
- ATCOs participated in Reference and Solution scenarios
- FMPs and ATCO supervisors participated in Solution scenarios only



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ASTRA Key RTS results

- Participants agreed that the hotspots were indeed complex
- Overall, ATCOs reported lower workload in Solution scenarios than in Reference scenarios
- In 67% of Solution scenarios, the preferred solution of the FMP – from those provided by ASTRA – was also the ‘preferred’ solution of ASTRA
  - The complexity score was an important factor for decision making
- Positive impact on en-route capacity, fuel efficiency and safety
- The ASTRA HMI was positively received
- Suggestions to improve HMI and make the solutions more operationally feasible

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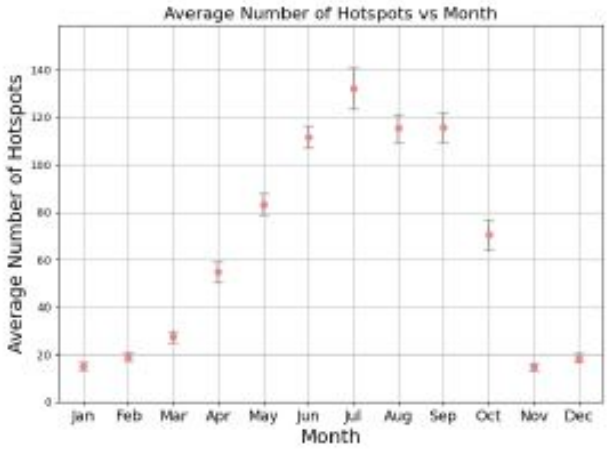
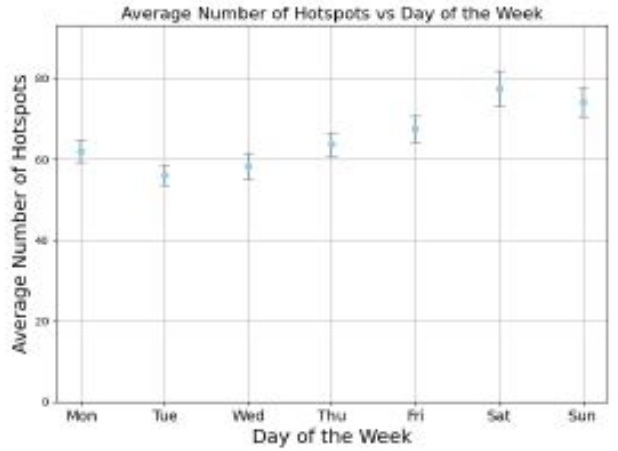
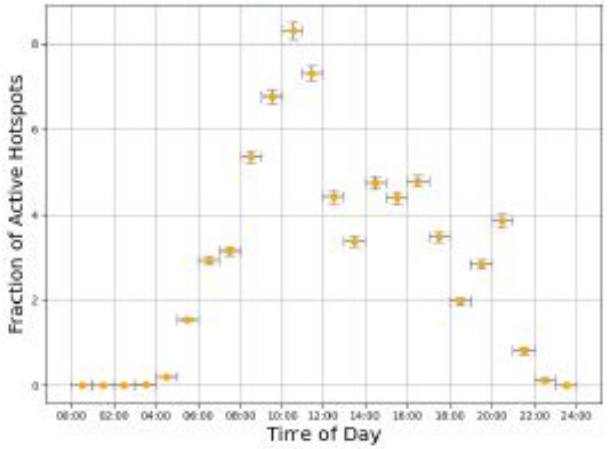
ASTRA Hotspot prediction







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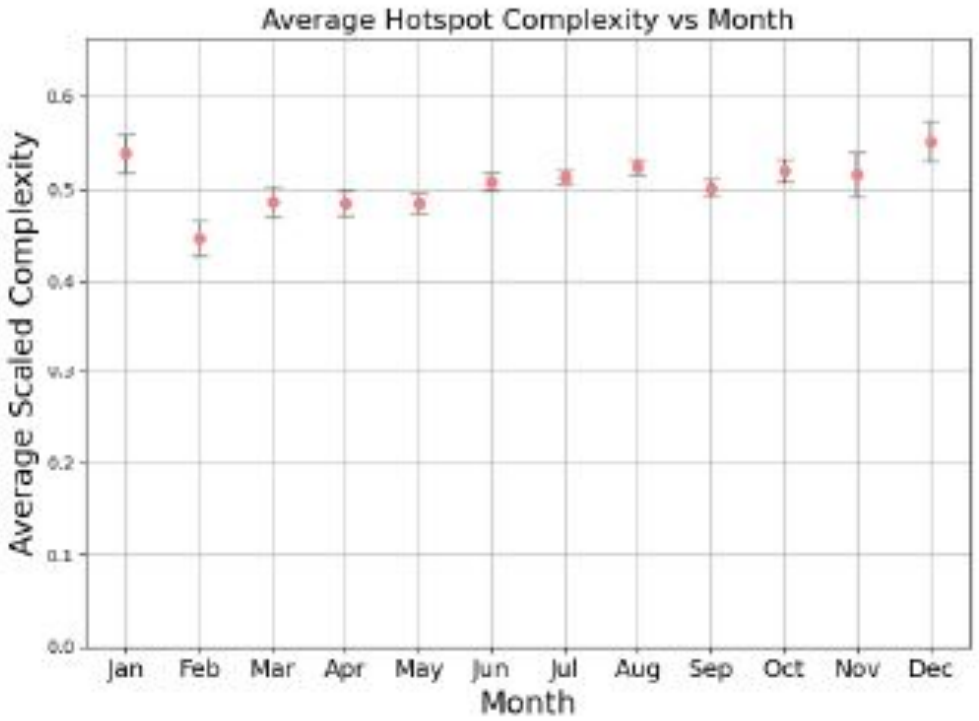
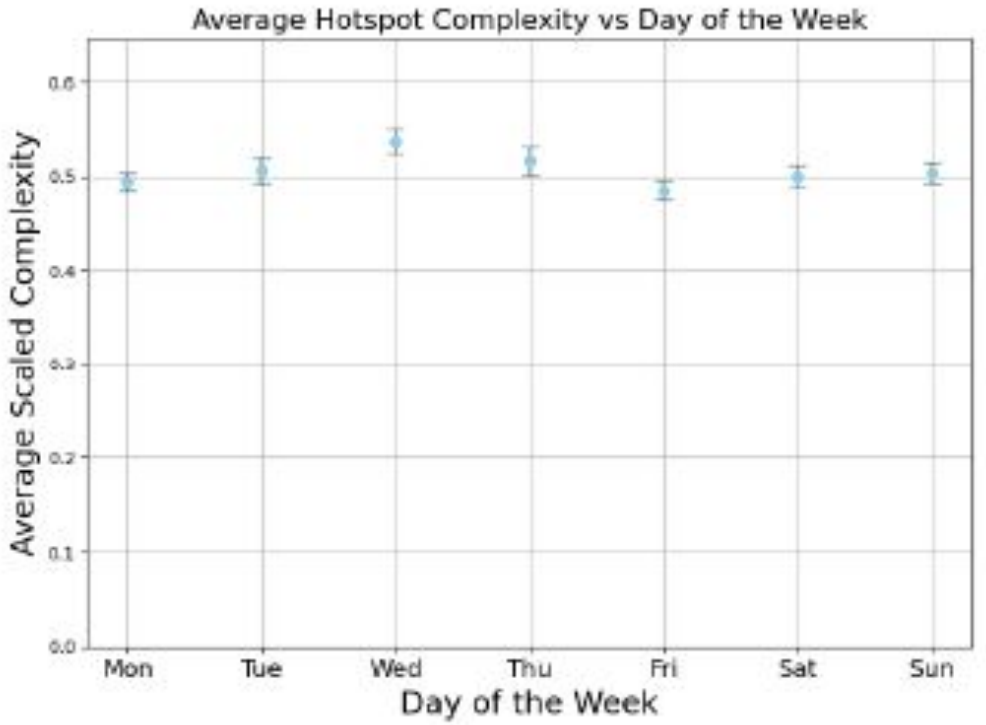
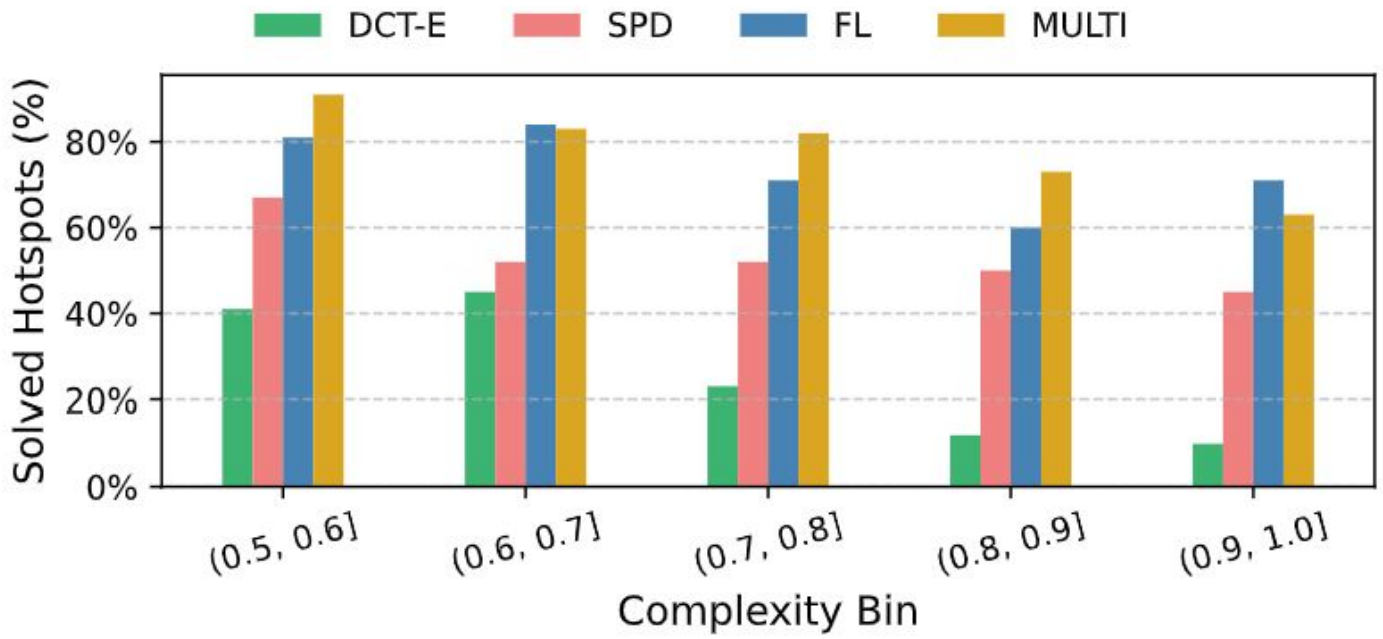
ASTRA Hotspot prediction

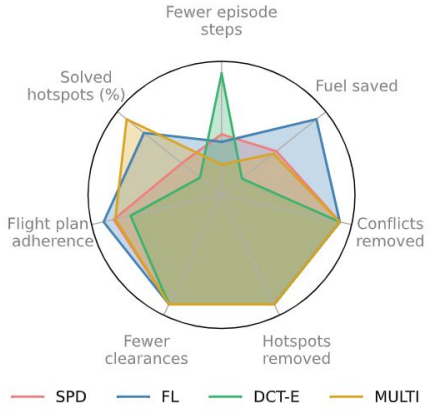




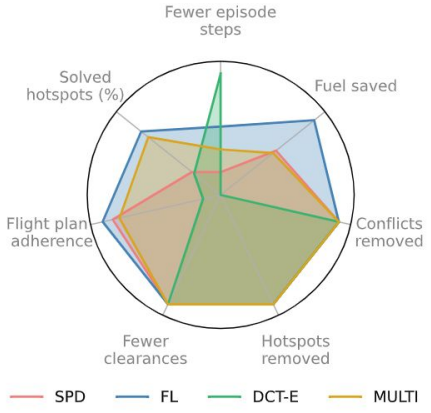
ASTRA Hotspot resolution



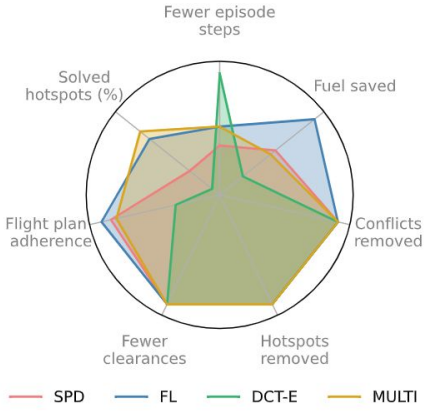
ASTRA Hotspot resolution



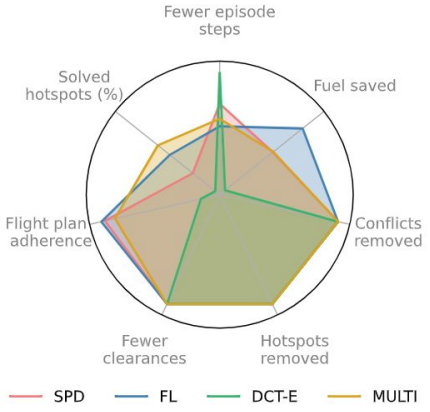
(a) 50-60% complexity bin.



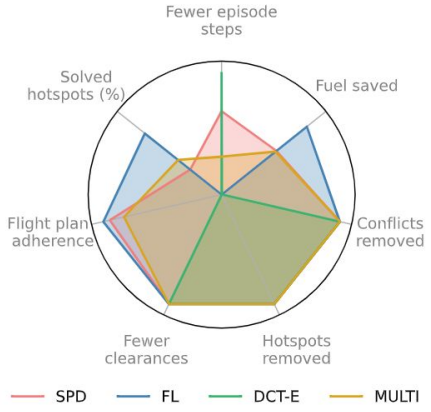
(b) 60-70% complexity bin.



(c) 70-80% complexity bin.



(d) 80-90% complexity bin.



(e) 90-100% complexity bin.

ASTRA

Conclusion

ASTRA Conclusion

- The proposed concept was positively received by end users
- ASTRA can predict and resolve hotspots in en-route airspace, in a way that has a beneficial impact on various KPIs
- Hotspot complexity was validated by operational experts
- The HMI supports end users with hotspot analysis and solution selection
- ASTRA meets TRL2 maturity criteria
- Several areas of future work identified to mature the concept/technology and address user feedback and exercise limitations

ASTRA

THANK YOU FOR YOUR ATTENTION

Jason Gauci
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https://www.sesarju.eu/projects/ASTRA
https://www.linkedin.com/company/astra-sesar/

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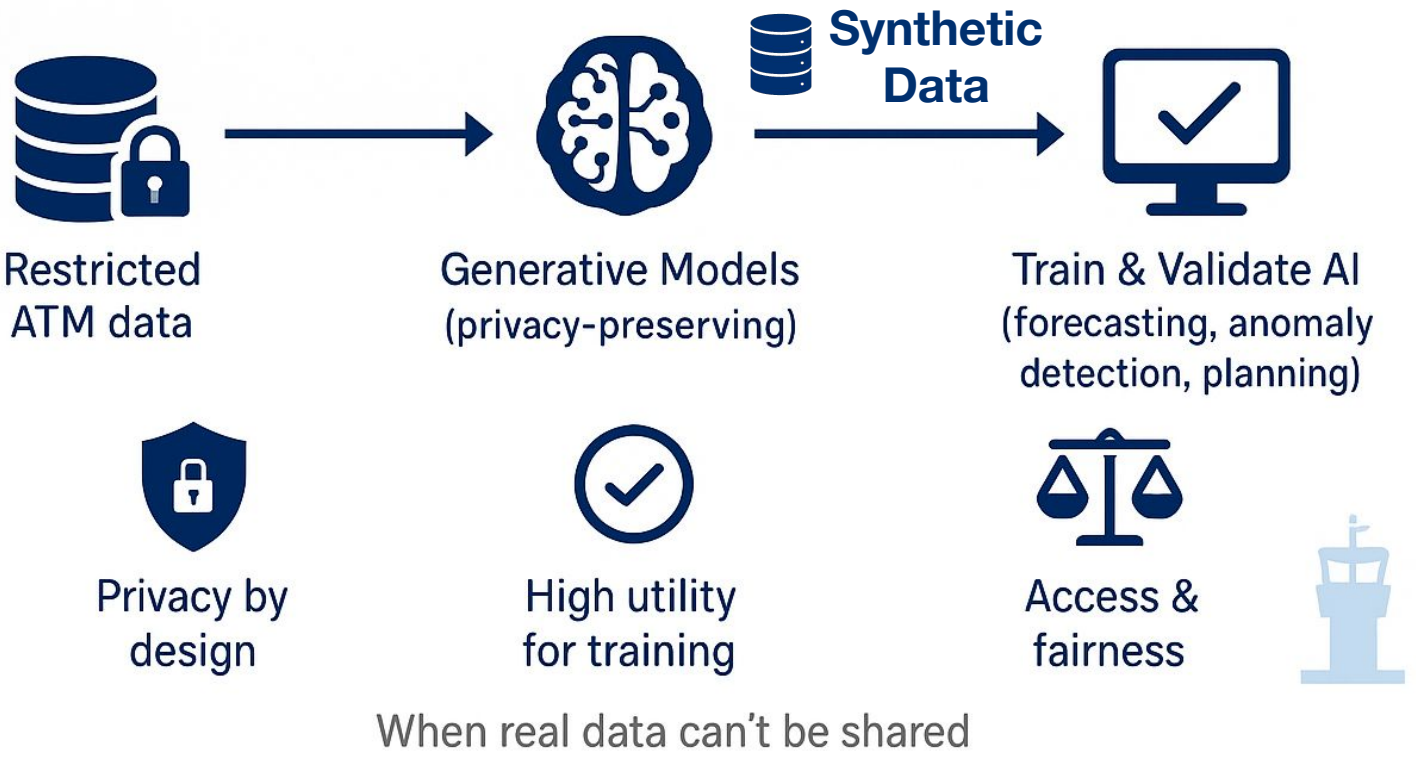
SynthAIr

Context & Mission

SynthAIr** objective is to leverage the potential of synthetic data for tackling structural **obstacles** such as **data access** and **scarcity**, **privacy** issues, for **accelerating** the **adoption** of **AI in ATM system



SynthAIr

Impact of synthetic data on selected use cases

UC1 Turnaround Time Prediction

Predicts the duration from aircraft in-Block to Off-Block, optimizing ground handling operations

UC2 Flight Delay Prediction

Addresses both primary and propagated flight delays

UC3 Passenger Flow Prediction

Generates synthetic data for terminal processes

UC4 Synthetic Traffic Generator

Creates realistic aircraft trajectories for ATM simulations

UC5 Flight Diversion Prediction

Predicts when aircraft cannot land at intended destinations

UC6 Schedule Prediction

Generates synthetic flight schedules for ML models

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SynthAIr aims to enhance ATM automation and simulation through **AI-driven synthetic data generation**, exploring six interconnected use cases:

SynthAIr

Type of generated data

UC1 Turnaround Time Prediction

Predicts the duration from aircraft in-Block to Off-Block, optimizing ground handling operations

UC2 Flight Delay Prediction

Addresses both primary and propagated flight delays

UC3 Passenger Flow Prediction

Generates synthetic data for terminal processes

UC4 Synthetic Traffic Generator

Creates realistic aircraft trajectories for ATM simulations

UC5 Flight Diversion Prediction

Predicts when aircraft cannot land at intended destinations

UC6 Schedule Prediction

Generates synthetic flight schedules for ML models

Tabular Flight Data

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SynthAIr

Impact of synthetic data on selected UCs and **type of generated data**

UC1 **Turnaround Time Prediction**
Predicts the duration from aircraft in-Block to Off-Block, optimizing ground handling operations

UC2 **Flight Delay Prediction**
Addresses both primary and propagated flight delays

UC3 **Passenger Flow Prediction**
Generates synthetic data for terminal processes

UC4 **Synthetic Traffic Generator**
Creates realistic aircraft trajectories for ATM simulations

UC5 **Flight Diversion Prediction**
Predicts when aircraft cannot land at intended destinations

UC6 **Schedule Prediction**
Generates synthetic flight schedules for ML models

Trajectory Flight Data

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How synthetic data is **generated** and **validated** for **realism** and **diversity**.

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Validation Approach for **tabular flight data**

- **Fidelity and Realism**
  - *Degree to which synthetic records **reproduce** both the **marginal properties** (individual feature distributions) and the **complex interdependencies** (pairwise and higher-order relationships) inherent in the **original data***

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Validation Approach for **tabular flight data**

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Validation of synthetic tabular data – **Fidelity and Realism**

- **Statistical similarity**

Kolmogorov-Smirnov Complement scores across synthetic data generators.

Chi-Squared Test scores across synthetic data generators.

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Validation of synthetic tabular data – **Fidelity and Realism**

- **Correlation Preservation**
  - Pearson Correlation Similarity
  - Spearman and Kendall Correlation
  - Correlation Matrix Distance
  - Mixed-Type correlation

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Validation of synthetic tabular data - **Fidelity and Realism**

- **Distribution similarity**

Continuous KL Divergence scores across synthetic data generators.

Discrete KL Divergence scores across synthetic data generators.

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Validation of synthetic tabular data - **Fidelity and Realism**

- **Likelihood-Based Metrics**

Bayesian Network Log Likelihood scores across synthetic data generators.

Gaussian Mixture Log Likelihood scores across synthetic data generators.

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Validation of synthetic tabular data - **Fidelity and Realism**

- **Detection-Based Metrics**

Logistic Detection scores across synthetic data generators.

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Validation Approach for **synthetic trajectories**

- **Source:** OpenSky Network + EUROCONTROL R&D Archive
- Generative Models **compared**: **TCVAE** and **TimeVQVAE**
- Models trained on the **same real trajectory dataset**
- Synthetic trajectories **generated** for evaluation
- Assessment along three axes:
  - **Fidelity** – how closely synthetic trajectories match real distributions
  - **Diversity** – coverage of the real trajectory manifold
  - **Realism** – indistinguishability from real trajectories under downstream classifiers

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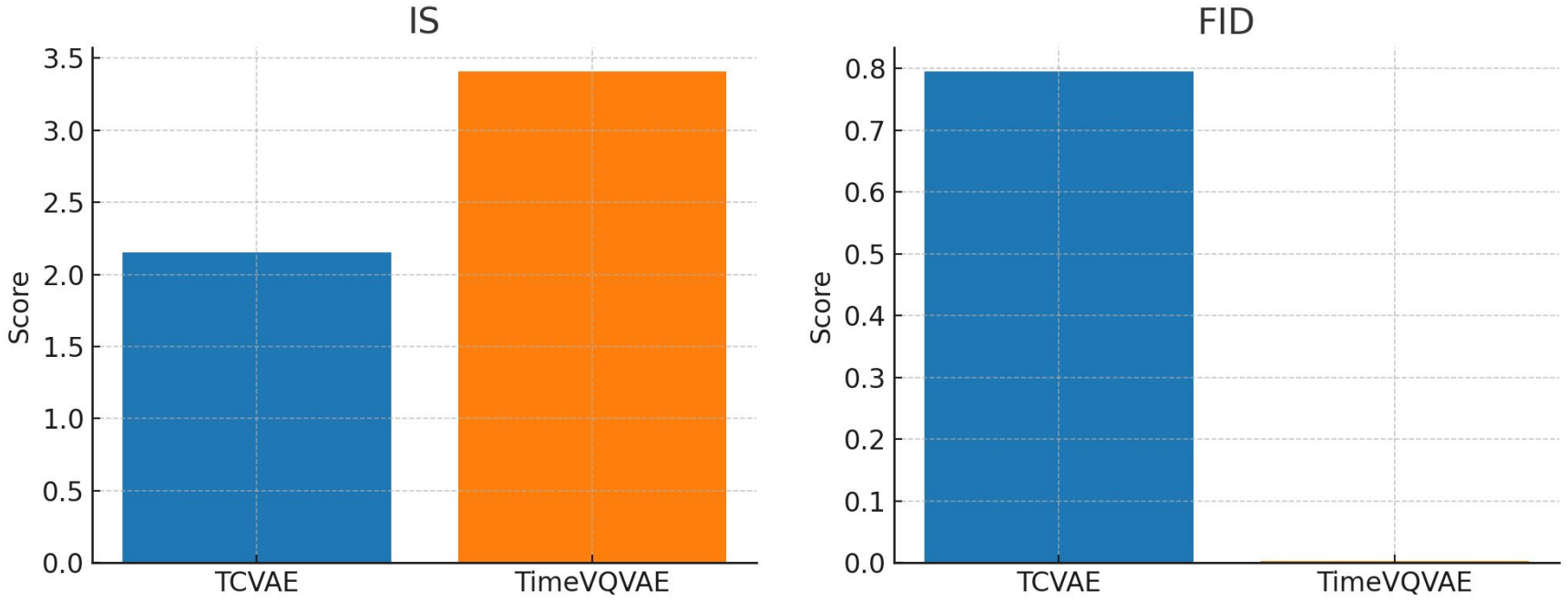
- **Quality Metrics -** how generated synthetic trajectories match the distribution of real data to their overall **diversity**
  - (↓) Fréchet Inception Distance (FID)
  - (↑) Inception Score (IS)



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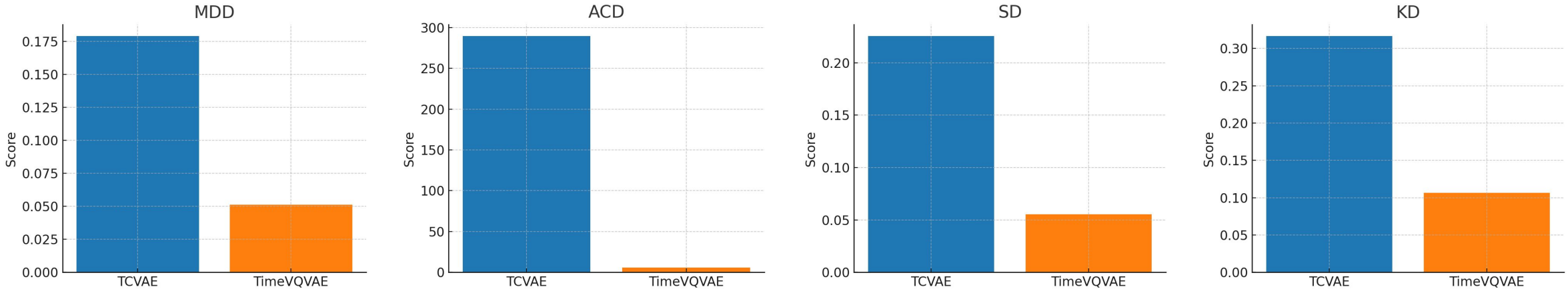
- **Statistical Metrics -** how closely the generated trajectories replicate not only the average behavior but also its **distributional** and **temporal** characteristics
  - (↓) Marginal Distribution Difference (MDD)
  - (↓) Autocorrelation Difference (ACD)
  - (↓) Skewness Difference (SD)
  - (↓) Kurtosis Difference (KD)



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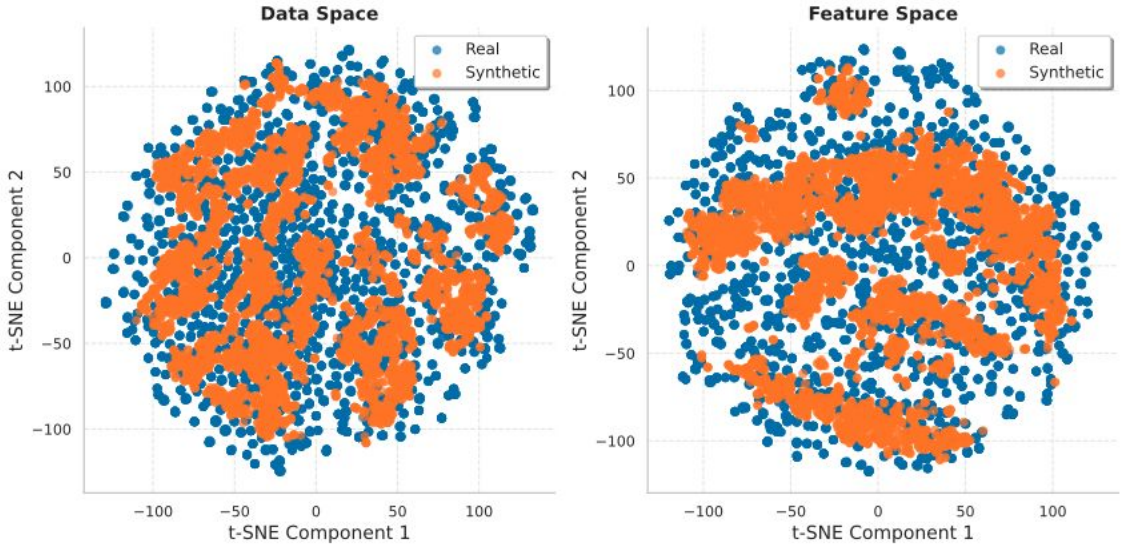
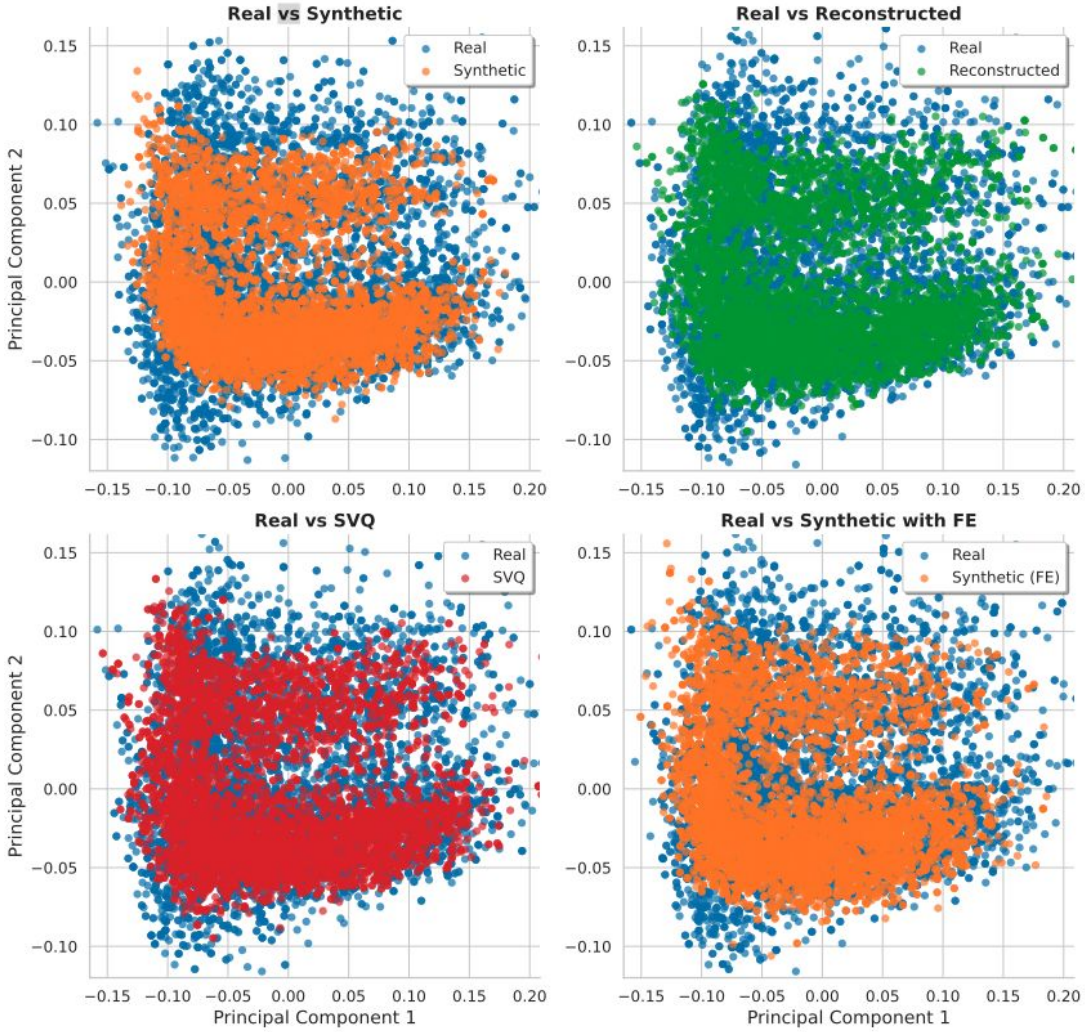
SynthAIr

- **Visual Inspection –** t-SNE and PCA



t-SNE Visualization of Real and Synthetic Flight Trajectories in Data Space and Feature Space.



PCA Visualization of Real vs Synthetic Trajectories.

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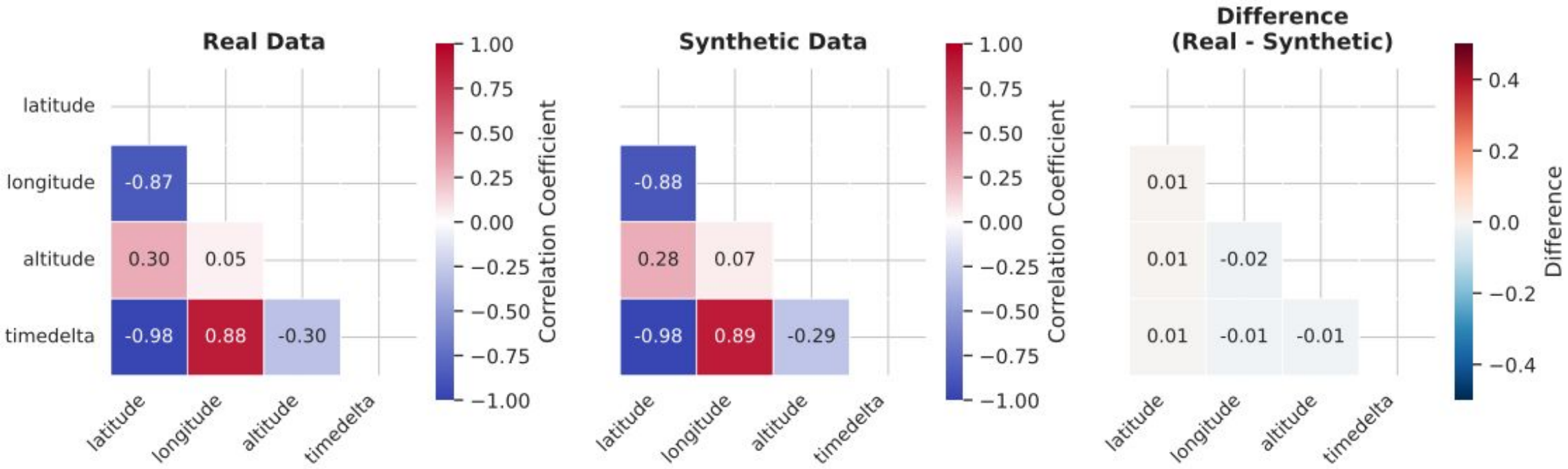
- **Visual Inspection –** Correlation Heatmaps



Correlation Heatmaps for Real and Synthetic Trajectories.

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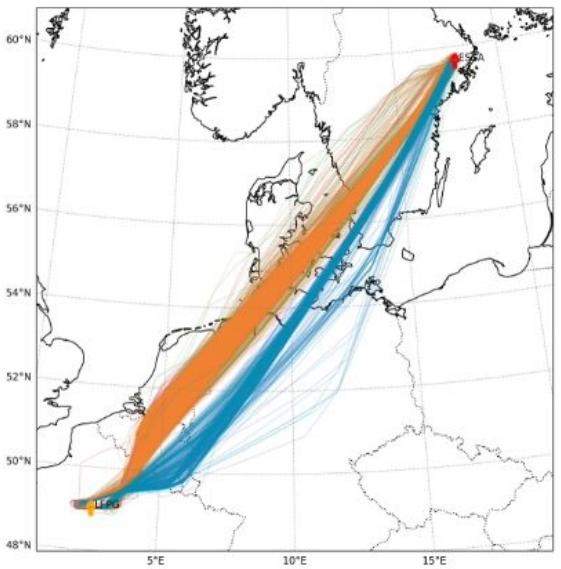
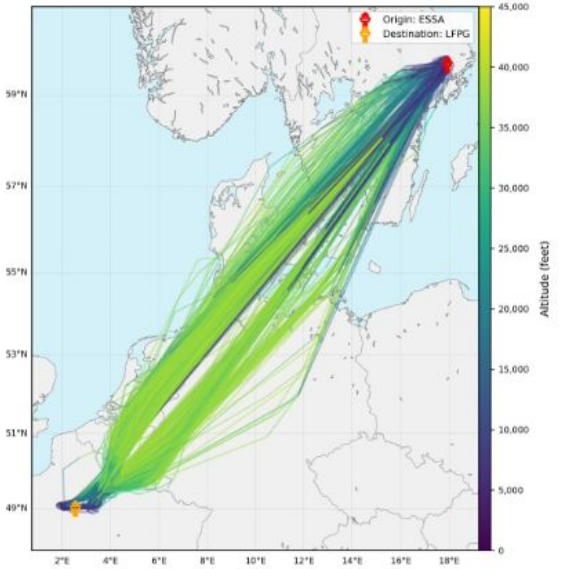
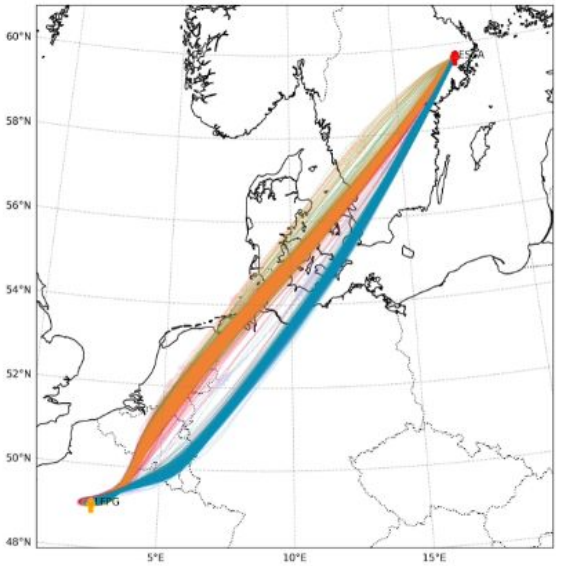
- **Visual Inspection –** Trajectory Visualizations
  - Comparison of Real and Synthetic Trajectories (ESSA to LFPG) in Terms of Spatial Routes and Altitude Profiles.



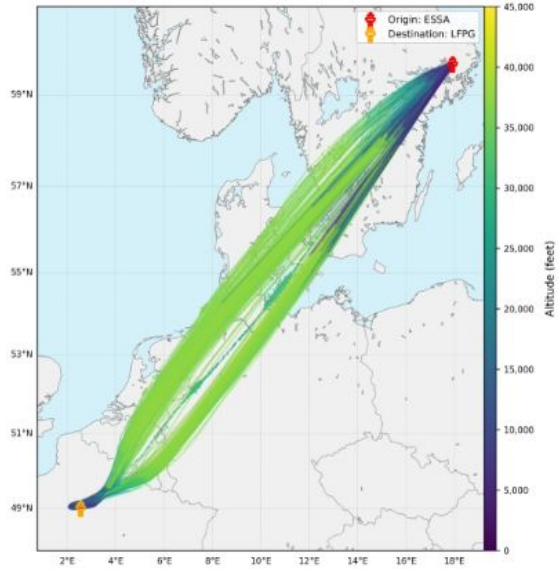
(a) Real Trajectories



(b) Real Altitude Profile



(c) Synthetic Trajectories



(d) Synthetic Altitude Profile

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Before/after example showing how synthetic data improved model training

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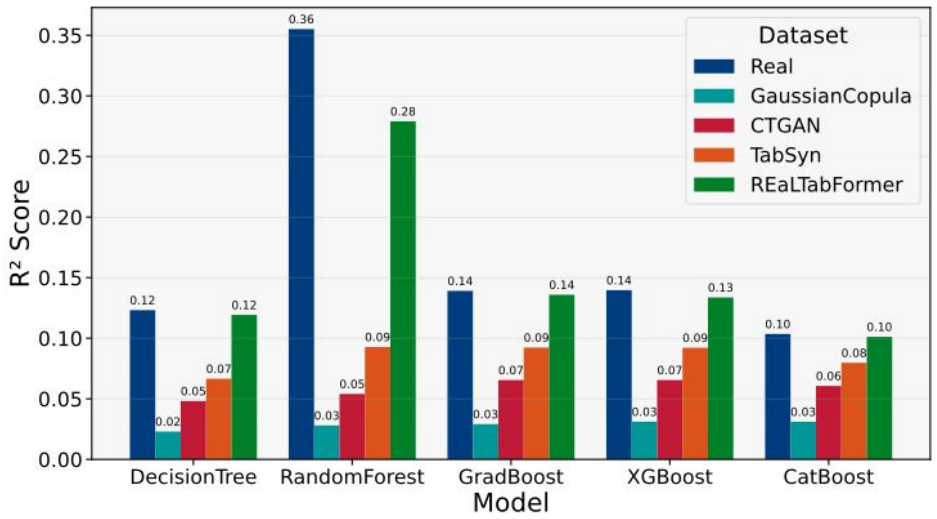
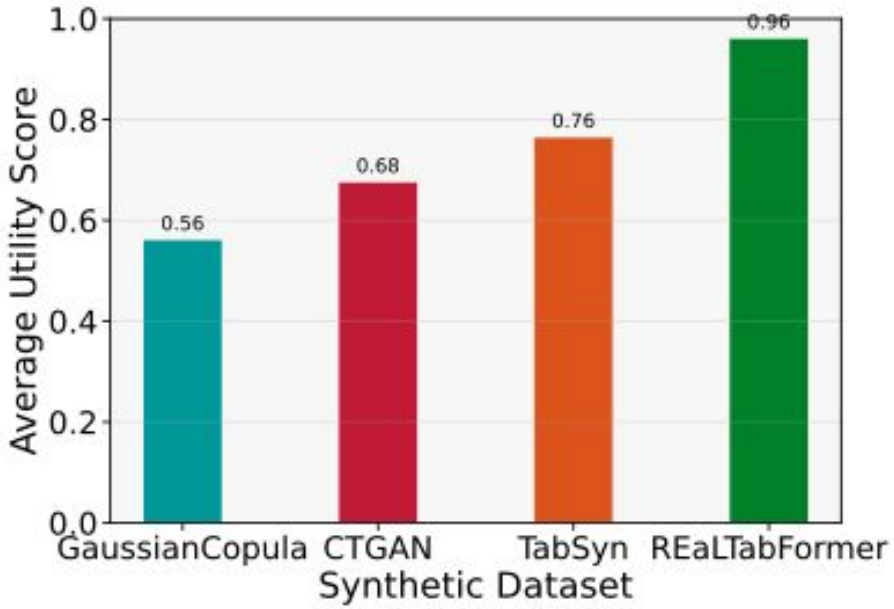
SynthAIr

- **Pre-tactical departure delay prediction is a challenging task – R^2** between 0.1 and 0.3



Coefficient of determination (R^2) for pre- tactical departure delay prediction across different models and synthetic data generators.



Average utility scores for pre-tactical departure delay prediction across synthetic data generators.

REaLTabFormerreaches about **96% of the performance of real data**

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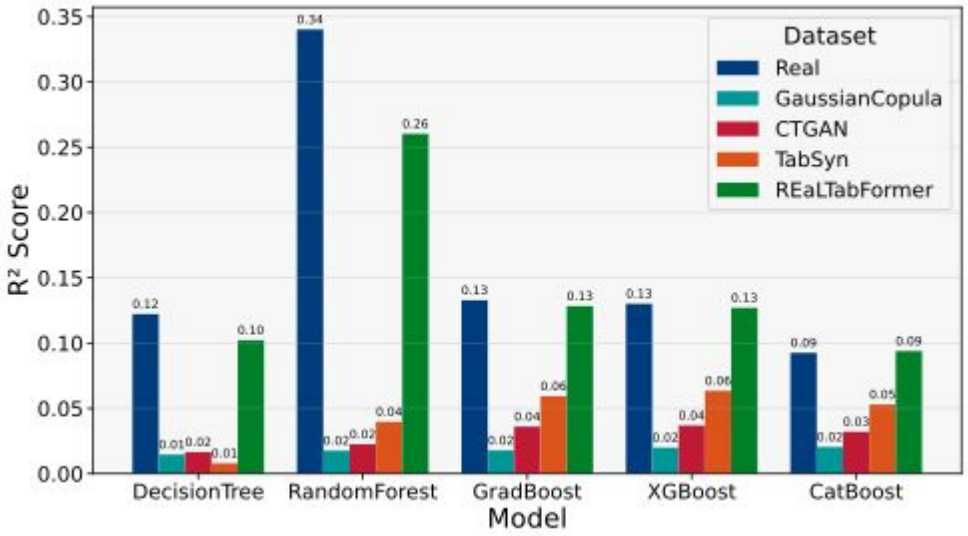
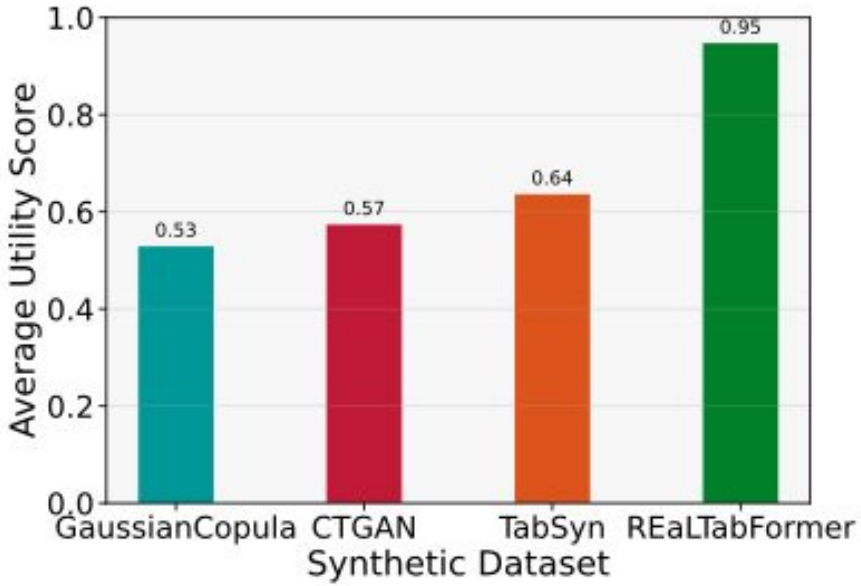
- **Pre-tactical arrive delay prediction is a challenging task – R^2** rarely exceeding 0.3



Coefficient of determination (R^2) for pre- tactical arrive delay prediction across different models and synthetic data generators.



Average utility scores for pre-tactical arrival delay prediction across synthetic data generators.

REaLTabFormerreaches about **95% of the performance of real data**

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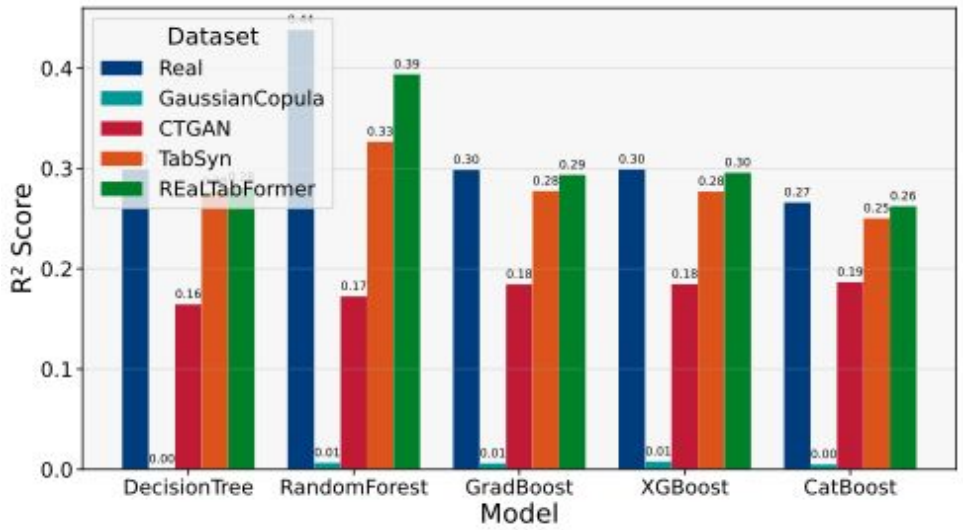
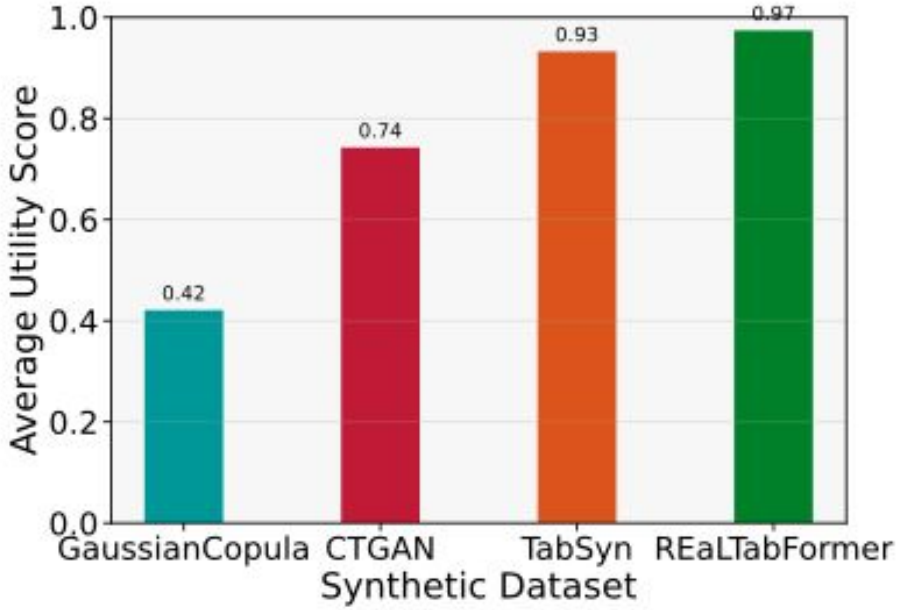
- **Pre-tactical Turnaround-Time Prediction is the less challenging task – R^2** around 0.27-0.44



Coefficient of determination (R^2) for Turnaround-Time prediction across different models and synthetic data generators.



Average utility scores for Turnaround Time prediction across synthetic data generators.

REaLTabFormerreaches about **97% of the performance of real data**

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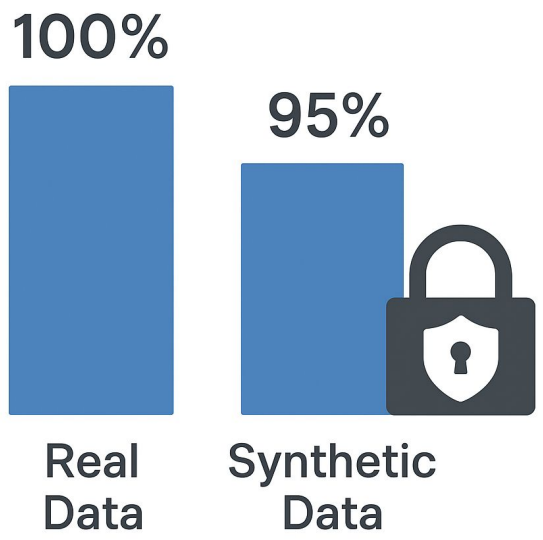
SynthAIr

*Synthetic data: **nearly real**, but **safe***

- Models trained on synthetic aviation data achieve **95–97%** of real-data performance.
- Preserves **operational insights** – same key drivers (*e.g., time-of-day, airport effects*).
- Enables safe access to data **without exposing sensitive records**.

UC1: Turnaround Time

UC2: Flight Delay



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Share any **surprising results**

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Surprise #1: Transfer learning enables **realistic synthesis** for data-poor airports

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SynthAIr

- **First systematic cross-airport transfer study for generative trajectory models**
  - Transfer learning enables **realistic synthesis** for data-poor airports

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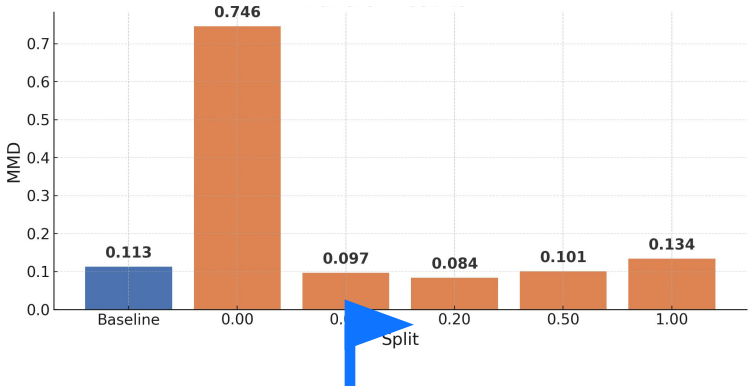
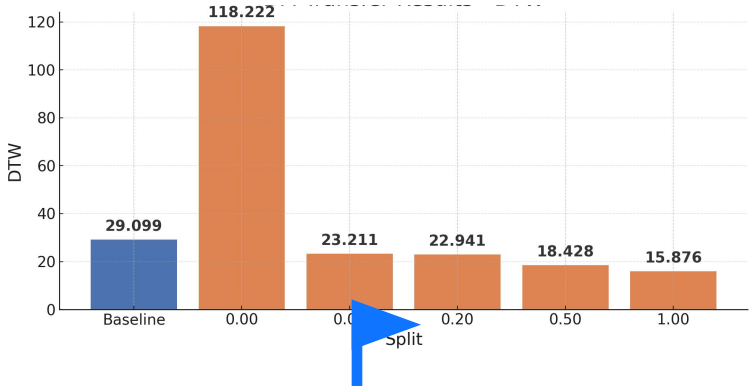
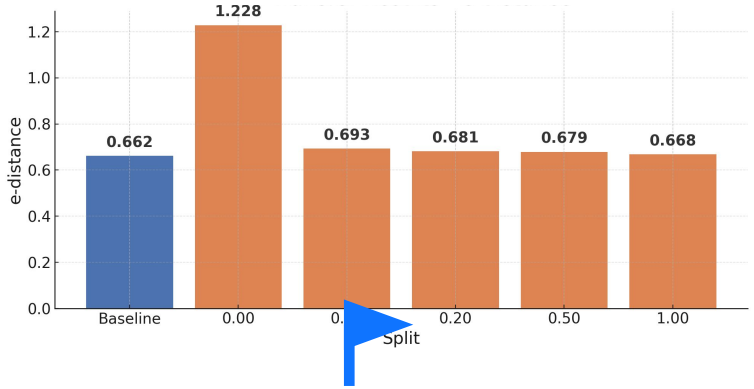
SynthAIr

- **First systematic cross-airport transfer study for generative trajectory models**
  - Transfer learning enables **realistic synthesis** for data-poor airports







- **5% data** already **outperforms the baseline** and significantly reduces MMD.
- **20%** further improves DTW and **all** the other metrics are **comparable to the baseline**

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Surprise #2: Generative models can go beyond data synthesis

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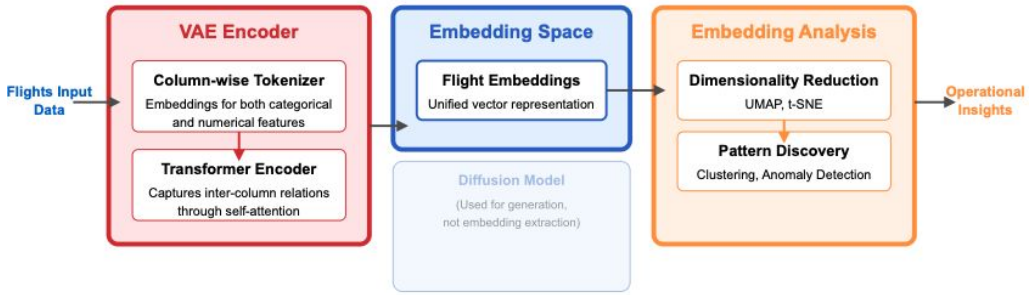
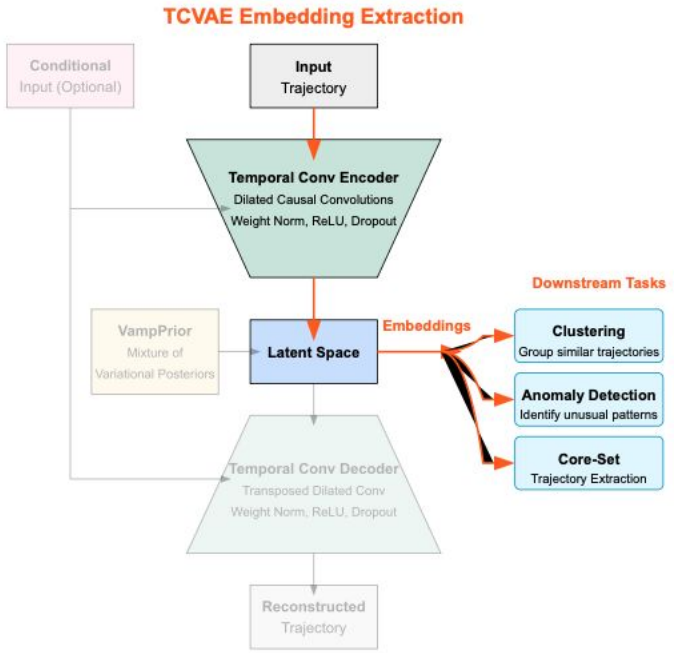
SynthAIr

- **Generative models can go <u>beyond data synthesis</u>**
  - Internal representation (embedding) enable new forms of operational analytics
- Example:
  - **TabSyn** for tabular flight data
  - **TCVAE** for flight trajectory data



TabSyn embedding extraction architecture



TCVAE embedding extraction for trajectories

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- **TabSyn** extracted **embedding** for **tabular flight data**
  - Route Operational Signature

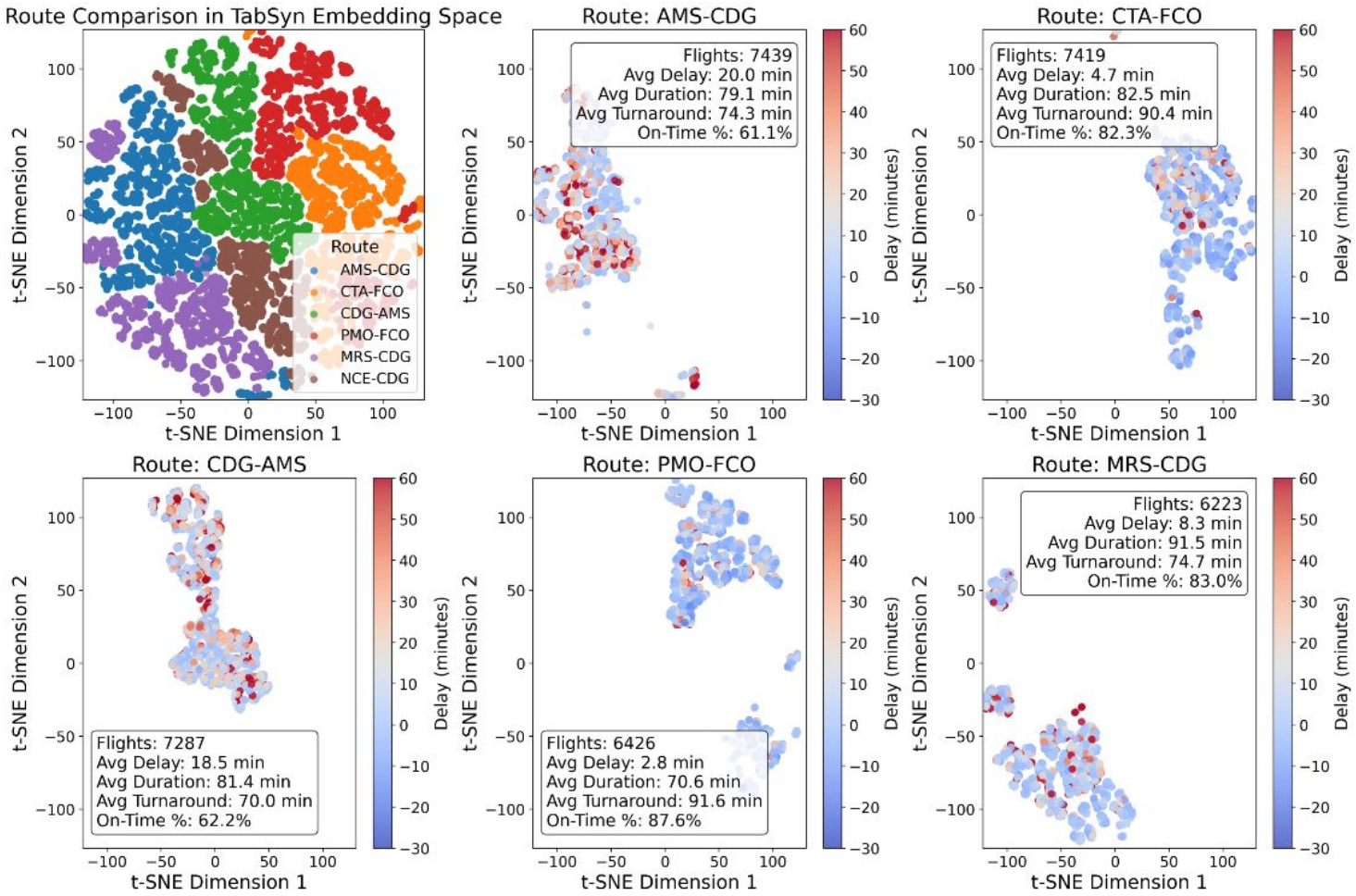

Figure 7. Route operational signatures in TabSyn embedding space.

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- **TabSyn** extracted **embedding** for **tabular flight data**
  - **Operational Network Analysis and Community Detection** in embedding space

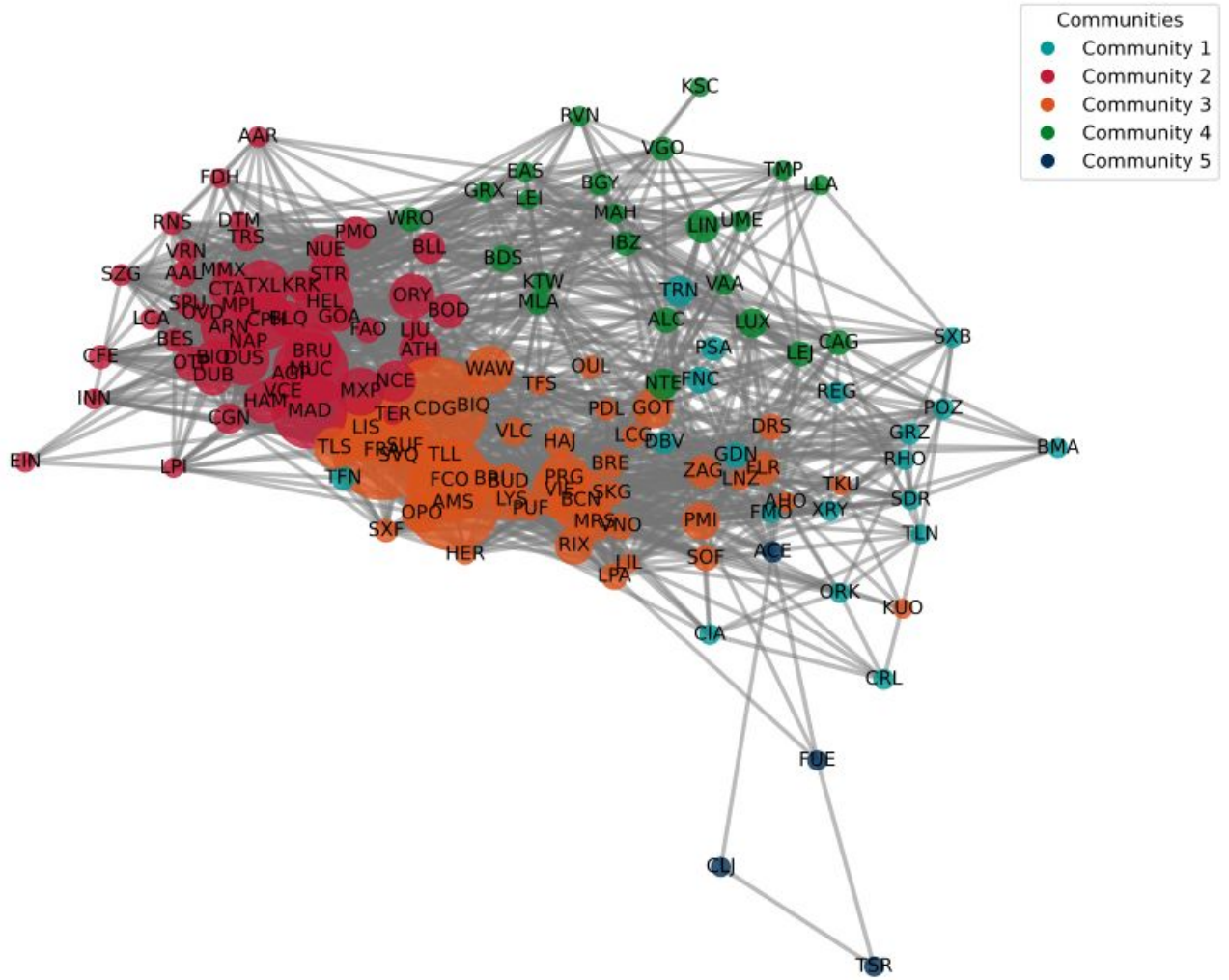

Figure 5. Airport network based on TabSyn embedding similarity.

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SynthAIr

- TabSyn extracted **embedding** for **tabular flight data**
  - **Outlier detection** in embedding space

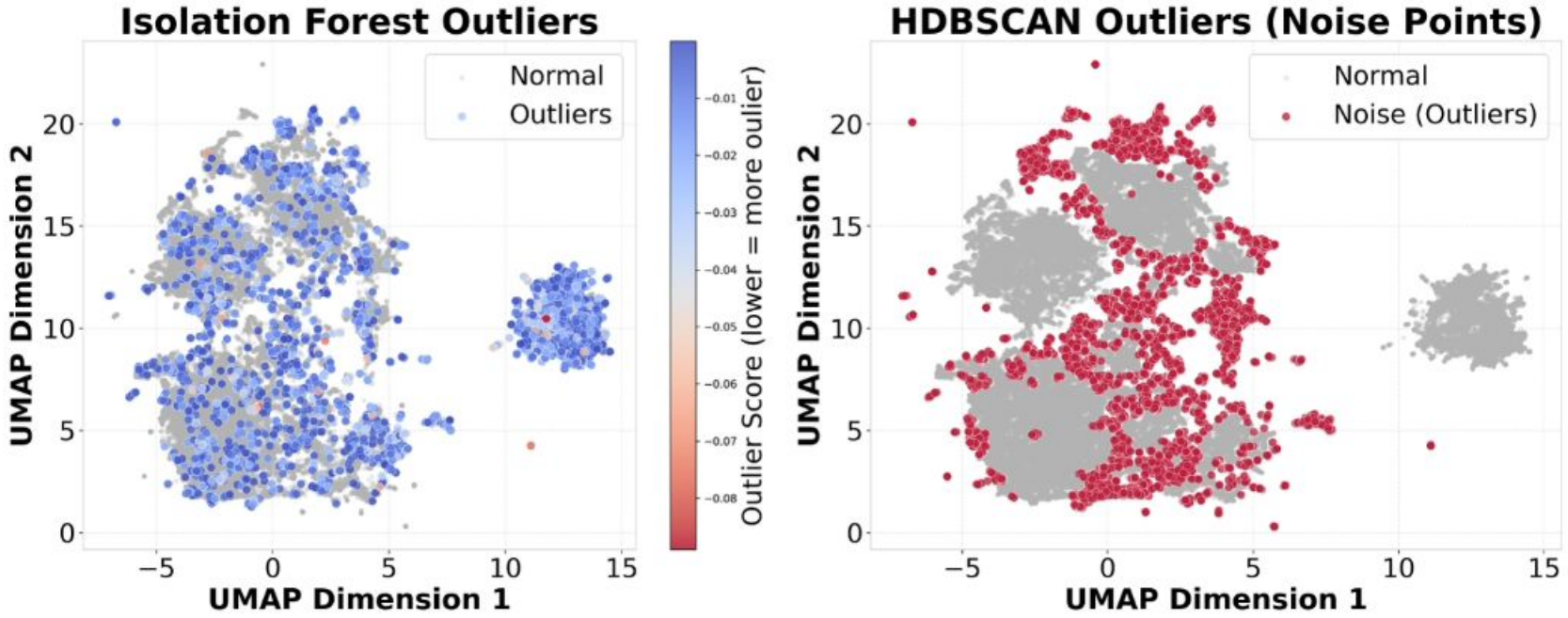

Figure 4. Outlier detection methods applied to TabSyn embeddings.

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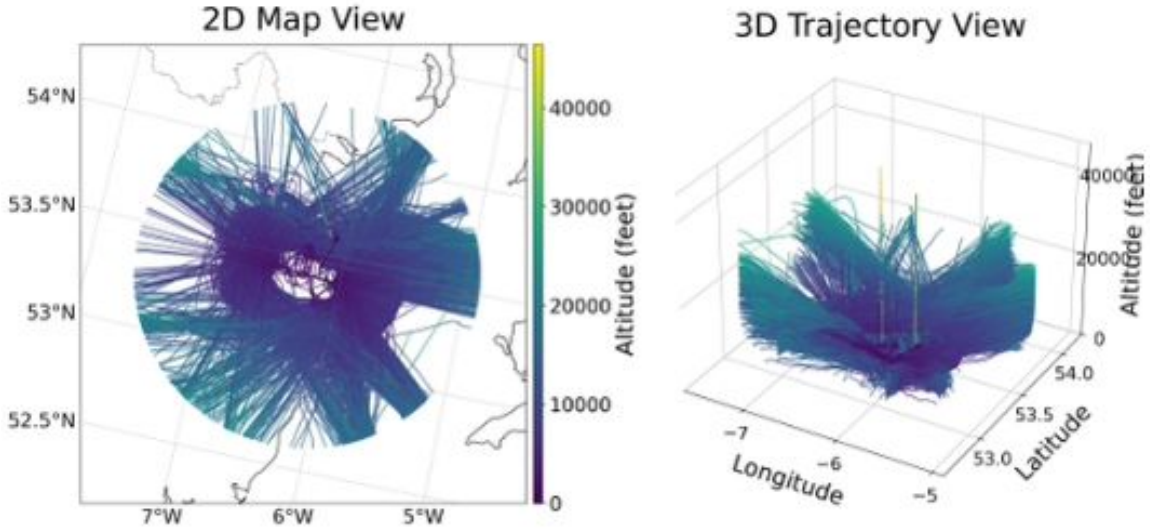
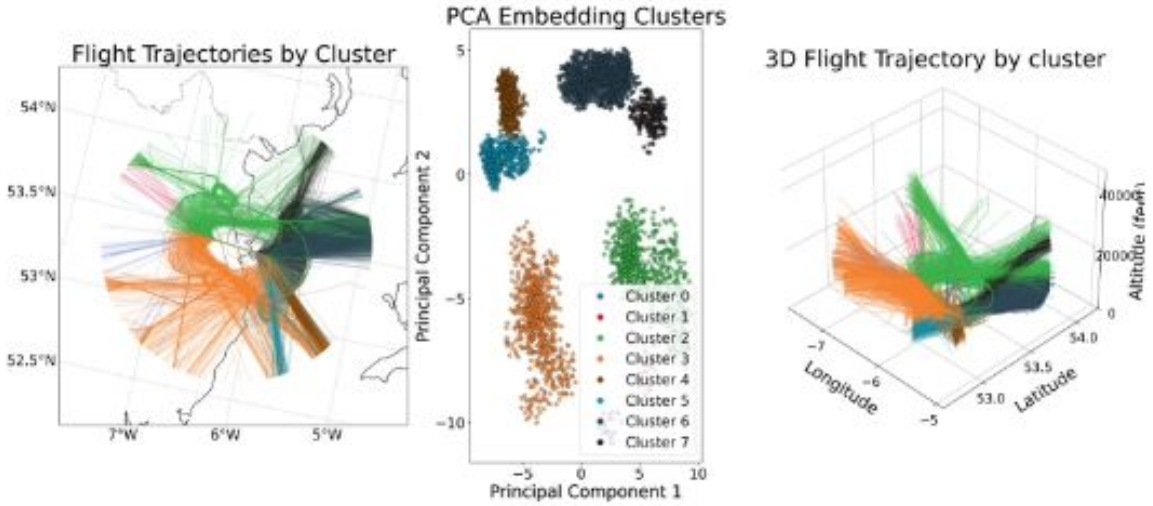
- TCVAE extracted **embedding** for **flight trajectory data**
  - Operational **Pattern Identification** Through **Clustering**.



(a) Raw Dublin approach trajectories



(b) Dublin approach patterns through clustering

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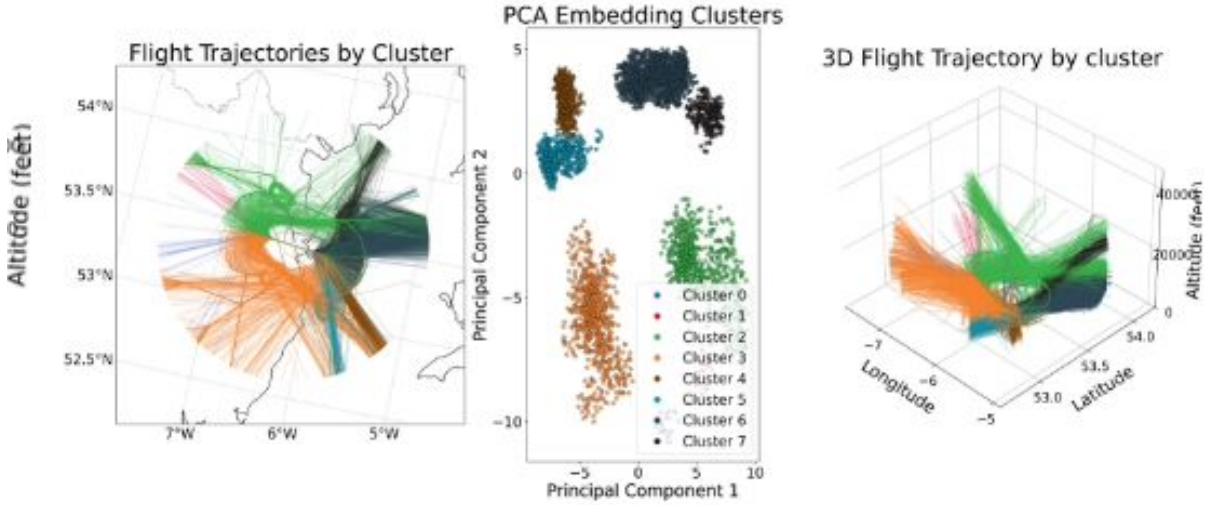
SynthAIr

- TCVAE extracted **embedding** for **flight trajectory data**
  - Representative **Trajectory Extraction** for Data **Efficiency**



(b) Dublin approach patterns through clustering

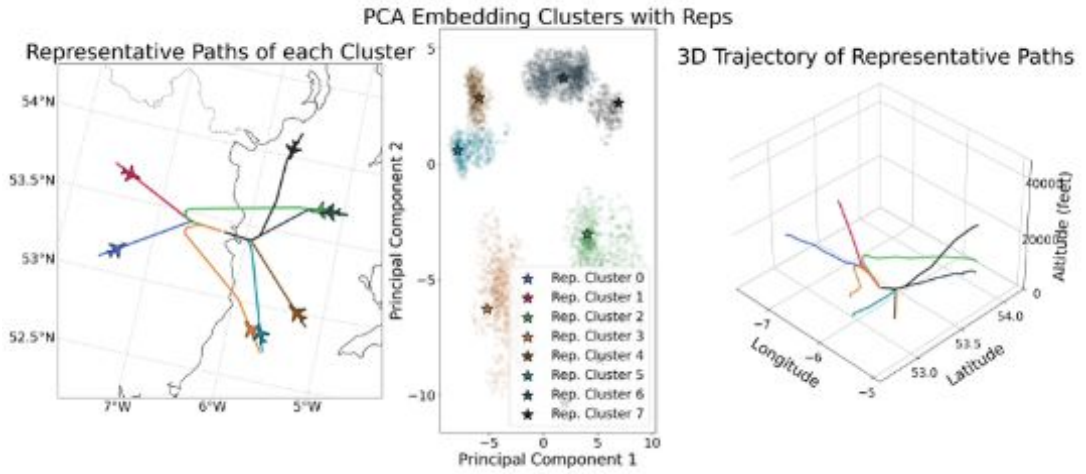


Figure 14. Dublin representative trajectory extraction.

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Thanks for your attention!

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