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Auto-Steer Taxi at Airport

Towards more automated airport ground operations

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Definition

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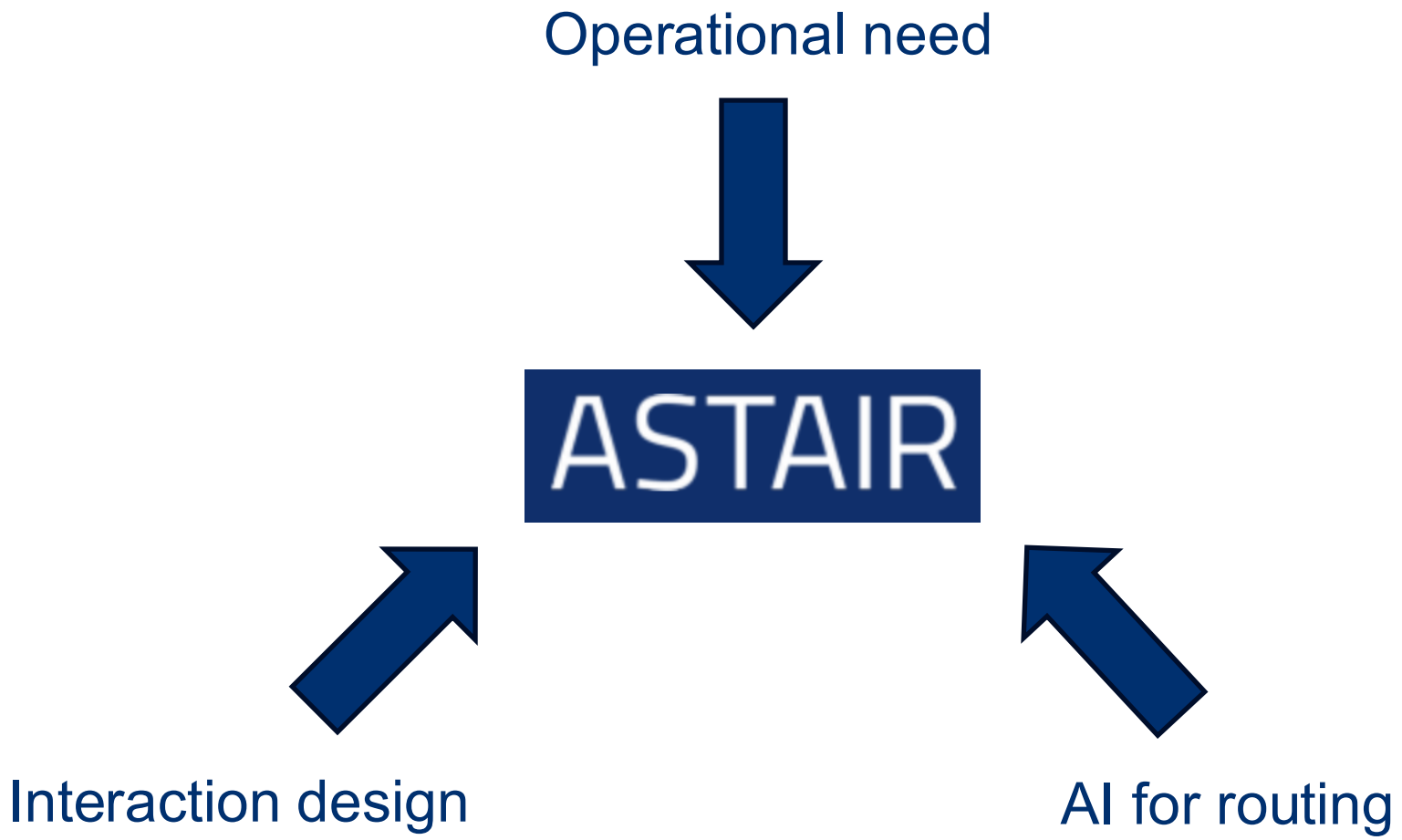
Definition



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Definition

In the near future, aircraft may be able to automatically follow a given route, either they are equipped with autonomous taxi or they are towed engines off by a tug.

The ASTAIR project will explore use cases where humans and AI collaboration can bring safer and more predictable ground operations.

New paradigm for ground management with multiple actors collaborating with an AI.

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Scope

- Large airports implementing A-CDM and A-SMGCS
- Aircraft and vehicles on the manoeuvring and trafic areas.
- Departures from push-back to runway entry.
- Arrivals from runway vacated to parking.
- Taxibot allocation and missions.
- Arrival and departure sequences as constraints.

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Levels of automation

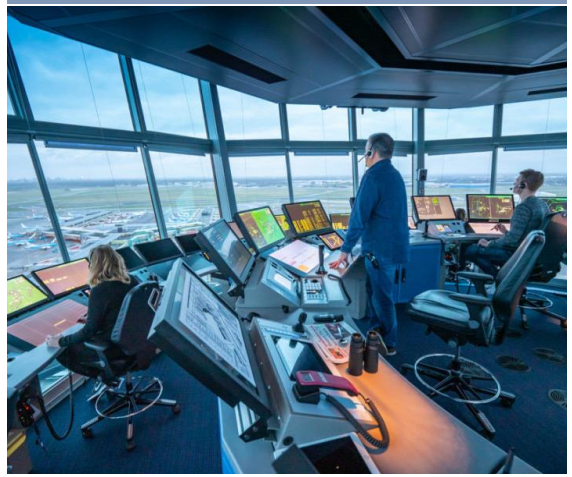
EASA's roadmap

Level 1: assistance to humans — 1A, 1B

Level 2: human-AI teaming — 2A, 2B

Level 3: advanced automation — 3A, 3B

current ATC system

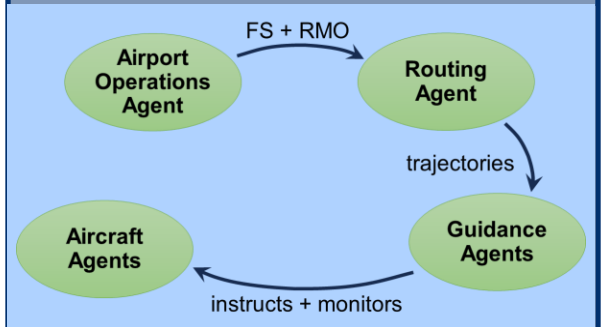


design of future system?

role & task allocation

effective teaming

MAS



multi-agent system model (fully automated ops)

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Use Cases

Use case 1 – Normal operation

- Use case 1a (UC1a) – Departure with Taxibot
- Use case 1b (UC1b) – Arrival with Taxibot

A-CDM gives schedule information, gates, runways, aircraft types
AI computes 20 mn of conflict free routing
Pilots are calling before moving
Ground ATCO supervises aircraft traffic
Tug Fleet Manager supervises TaxiBots traffic

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Use case 2 (UC2) – Normal operations with rescheduling

For some reasons, pilots, ground handling or airline operations update off block time on A-CDM or AMAN updates ETA.
AI recomputes with the new data

Use case 3 (UC3) – Arriving traffic with occupied parking

The previous aircraft at the designated gate is late for departure.
AI shall detect the issue and propose different solution.
AI needs help from ATCO to get more contextual information

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Use case 9 (UC9) – Departure flight with sick passenger

A departure flight has started the normal procedure,
it is already taxiing and sometime before reaching the runway entry,
the pilot calls ATC to request to go back to parking because of a sick passenger on board

Those use cases have been actually tested

Use Cases

- Use case 4 (UC4) – High level taxi strategy tuning
- Use case 5 (UC5) – Automation failure
- Use case 6 (UC6) – Runway mode of operation modification
- Use case 7 (UC7) – Departure remote holding (push and hold)
- Use case 8 (UC8) – Arriving flight with technical issue

Those use cases were investigated. A deliverable is dedicated to their presentagtion

A Multi Agent System at the core of ASTAIR AI

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Multi Agent System

- Yes it is AI !
- MAS model over classical routing algorithms for scalability.
- No deep learning model is capable of managing so many features, and we cannot take the risk of AI hallucinations.
- We are looking at an automated system (whatever the embedded AI is)

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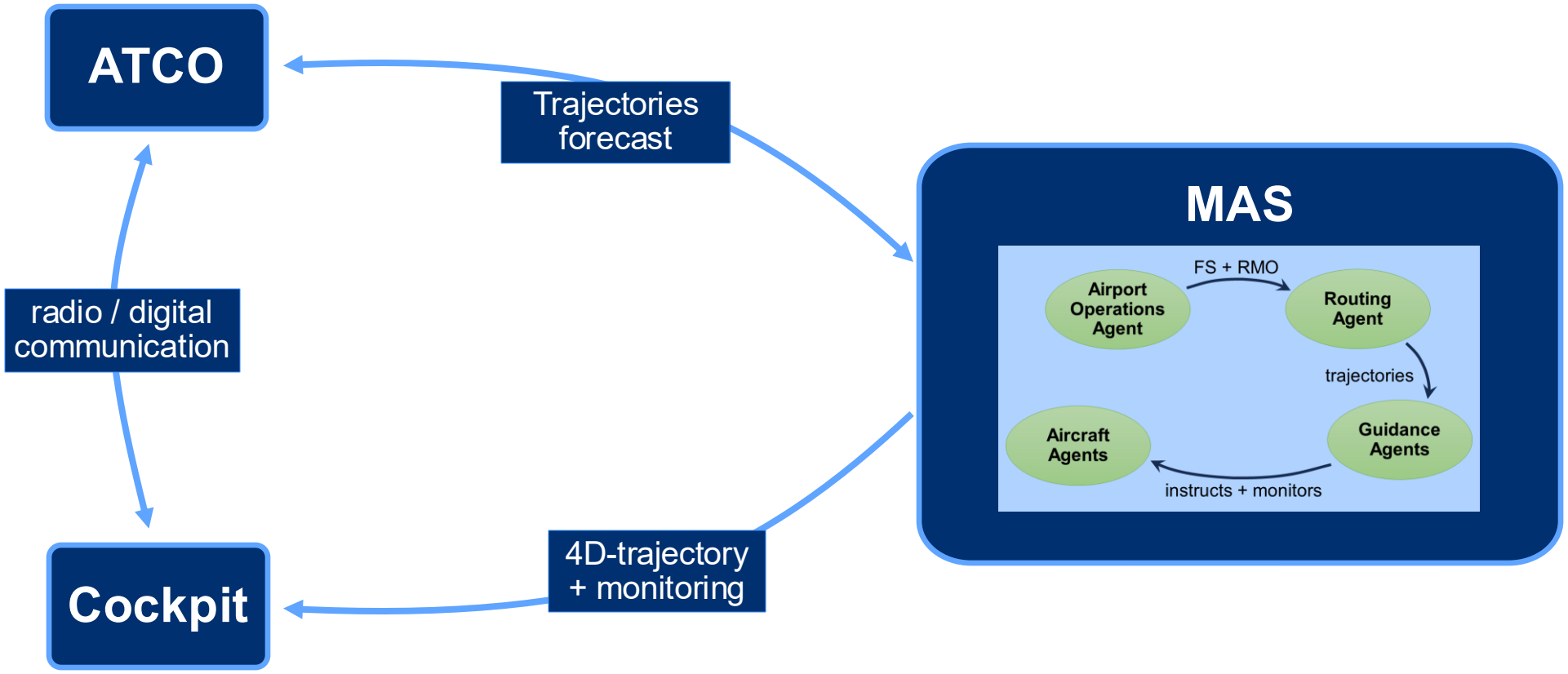
Multi Agent System



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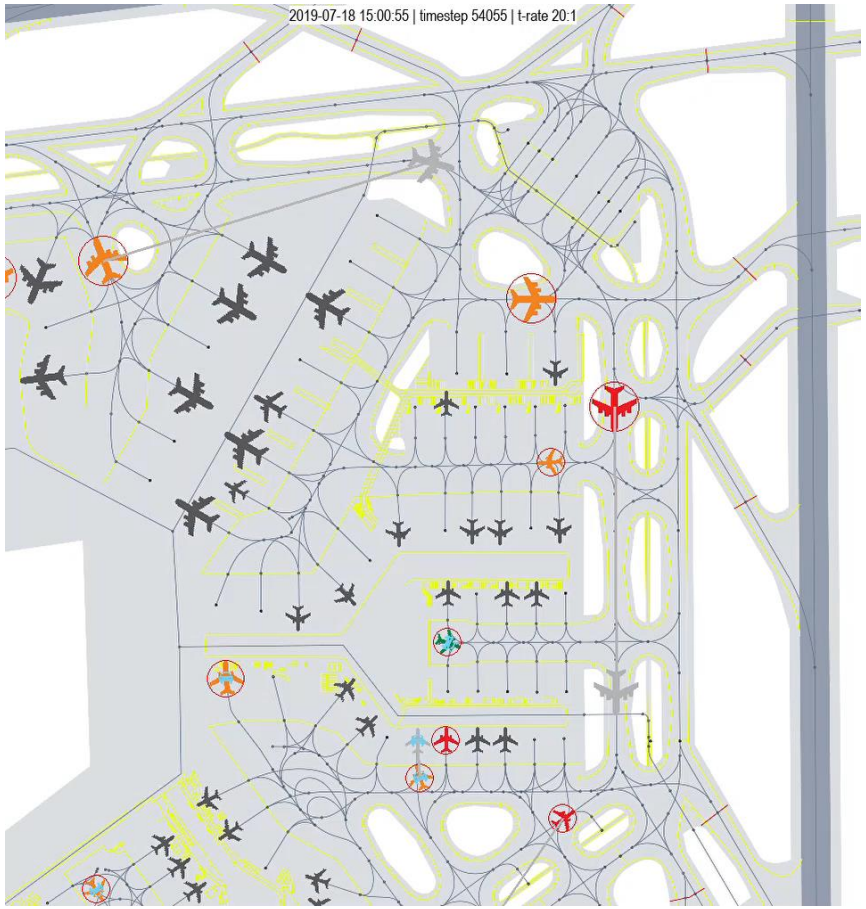
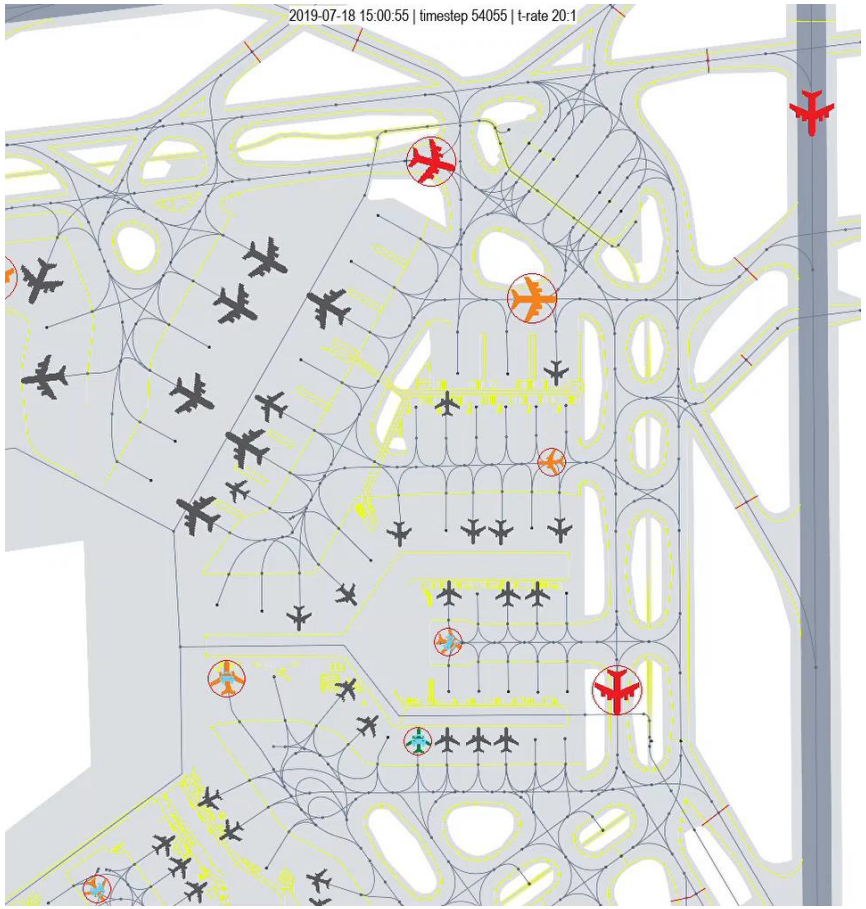
Multi Agent System





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WP 3: Interaction design

Goal: Designing Interfaces and Interaction for supervising and controlling aircraft movements on a highly automated airport

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WP 3: Interaction design

Identified requirements (via workshops with ATCOs)

- Support Understanding of Automation Plans (Supervise - level 3)
- Leverage Expertise to Improve System Performance (Collaborate - level 2)
- Support Human Authoring, Handover and Takeover (Control - level 1)
- Enable Several Parallel Levels of Automation (Parallel levels)
- Dynamic Level of Automation Transition (Flexibility)

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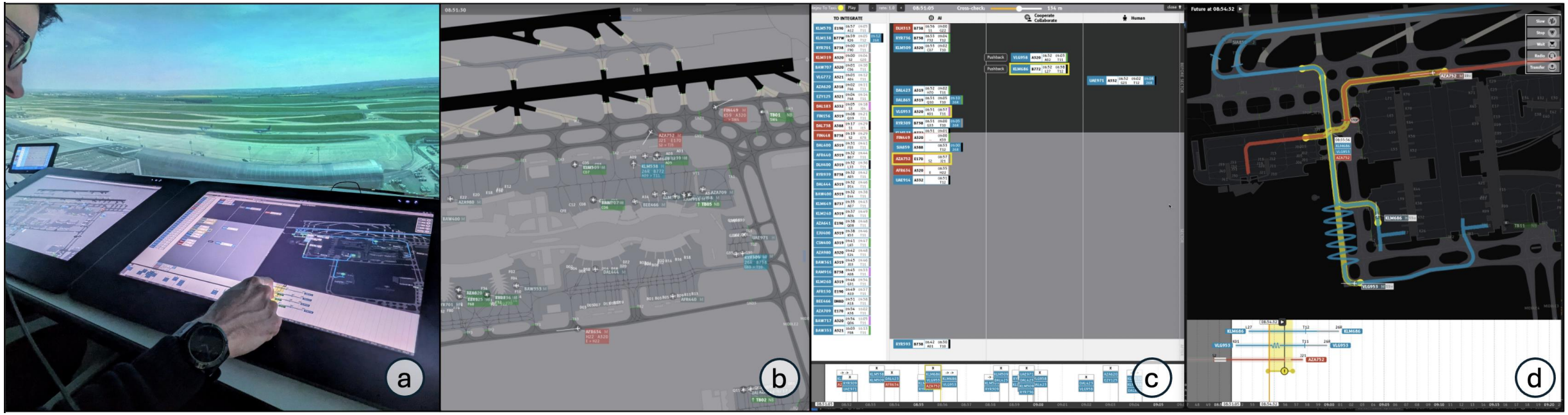
WP 3: Interaction design



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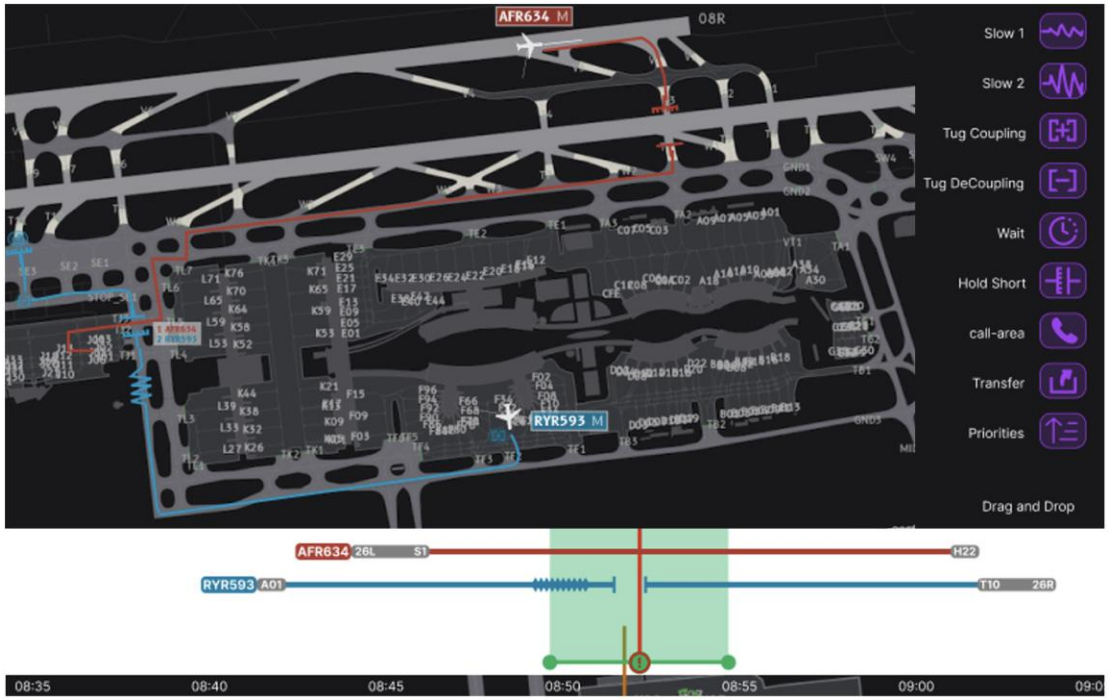
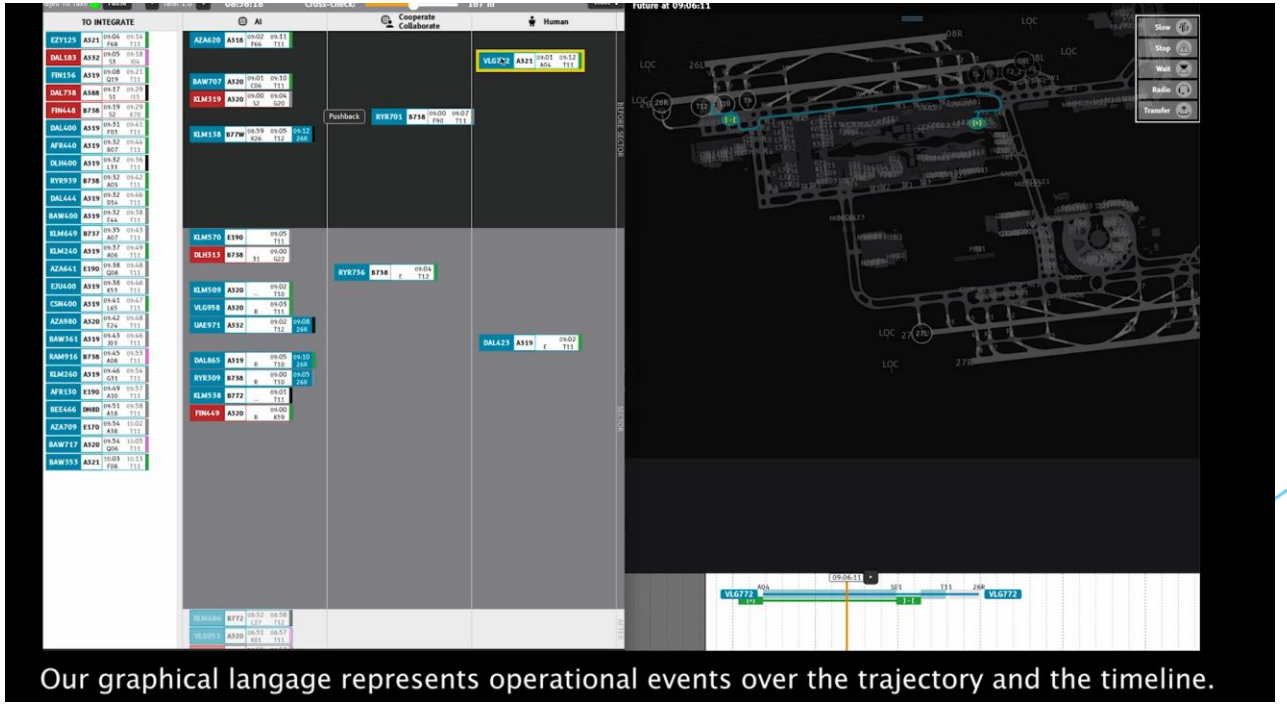
WP 3: Interaction design

Domain Specific Graphical Langage (DSGL) facilitating mutual understanding and edition of automated plans

- The DSGL represents operational events over the trajectory and the timeline
- Interactions supporting inspection and edition





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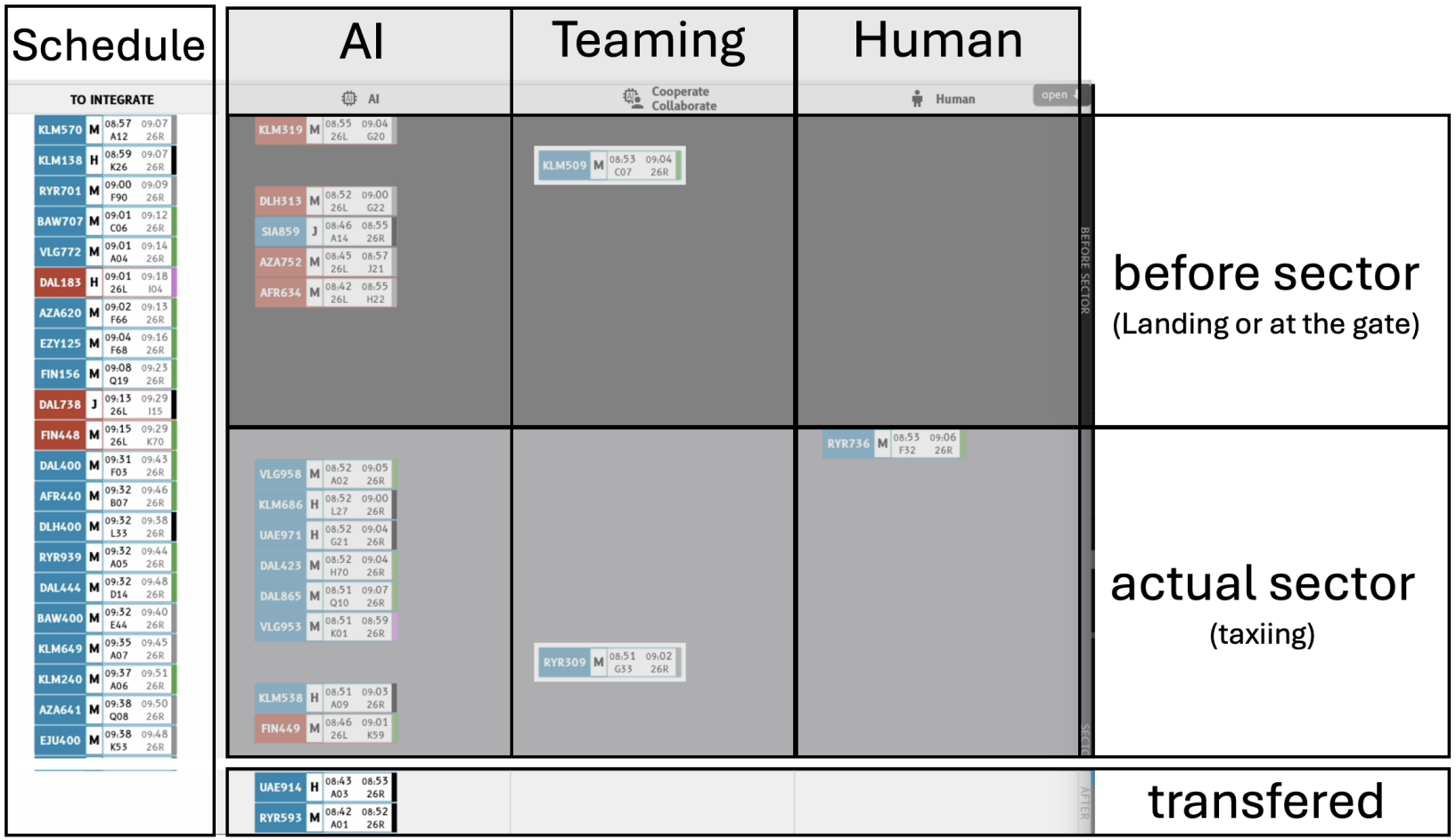
WP 3: Interaction design



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Cross-checks enhancing collaborative surveillance and fine tuning

- Explicit temporal and spatial representations of risky situations
- Interactions to adjust the plan

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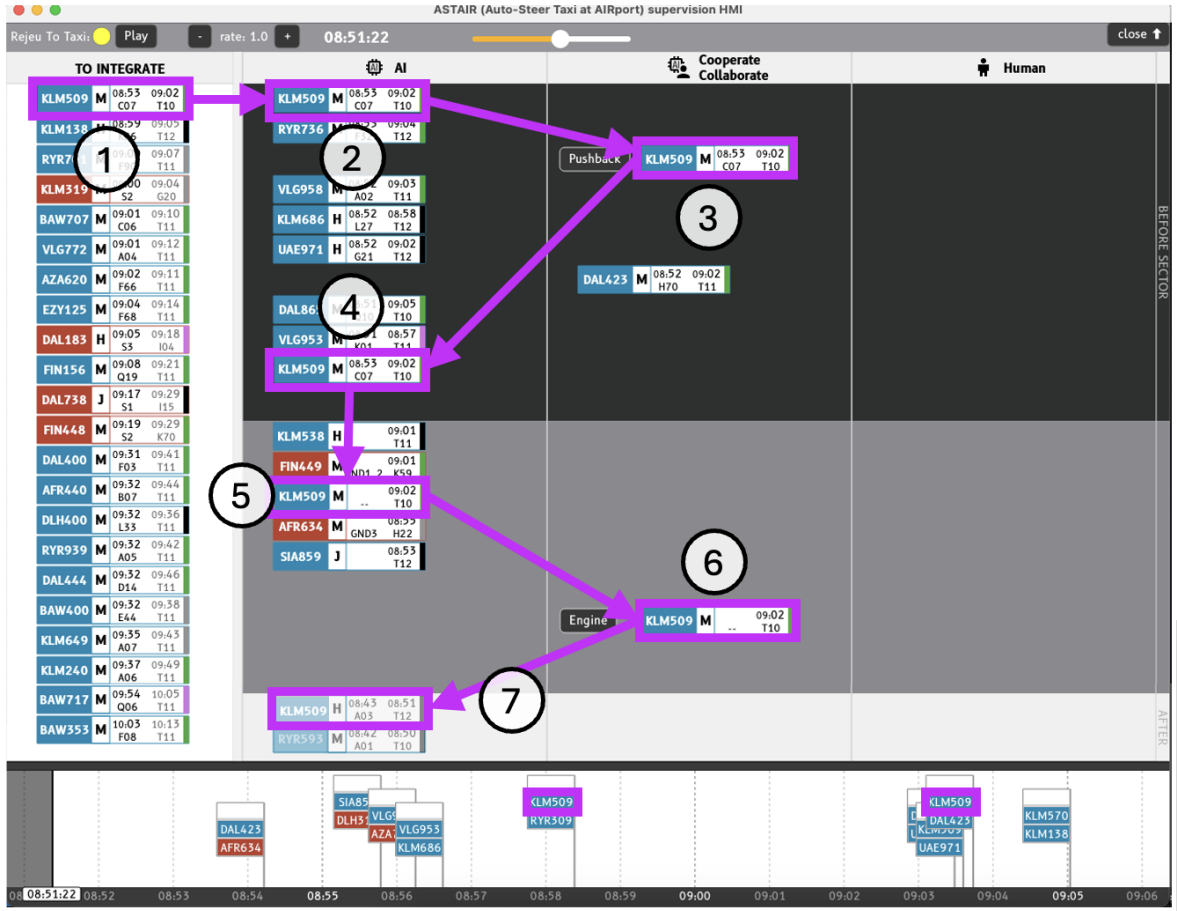
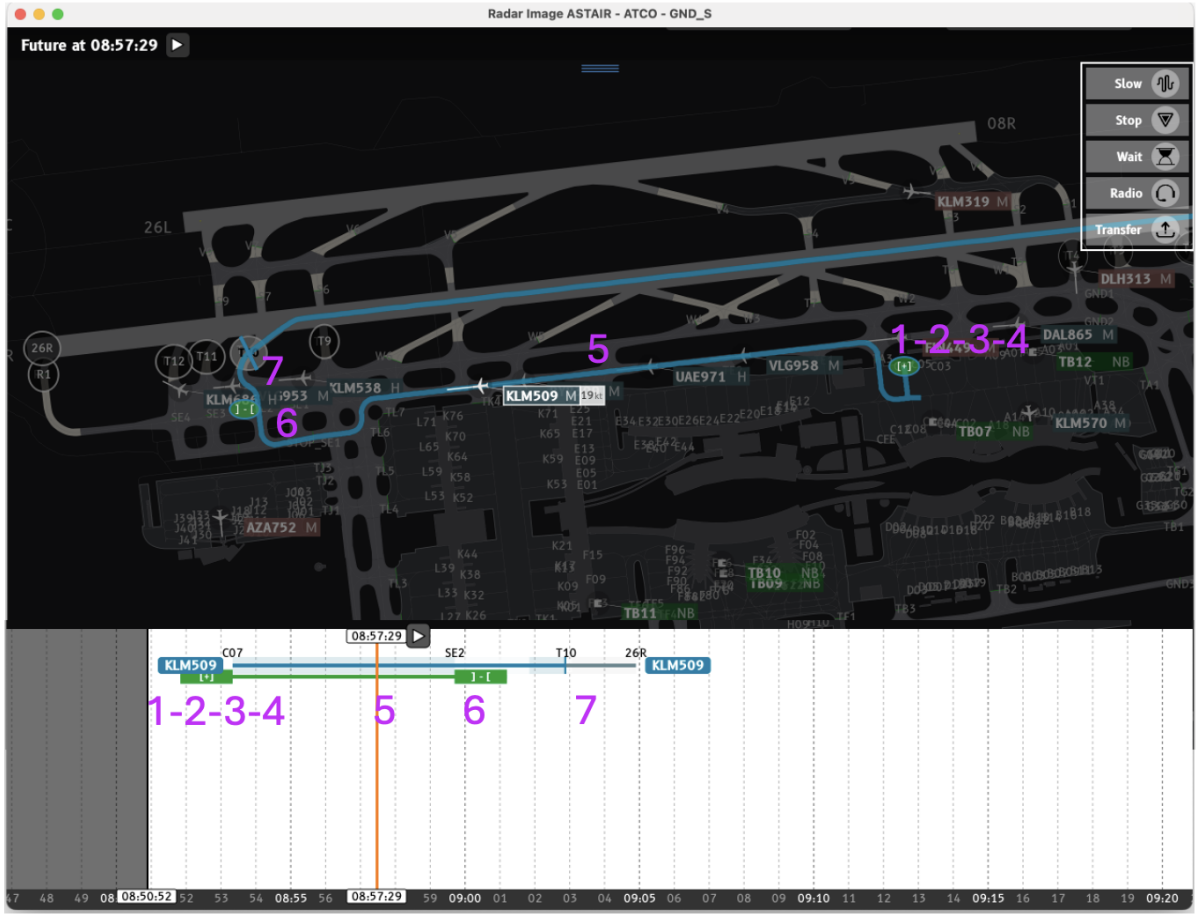
WP 3: Interaction design





Design principles:

- Provide per-unit control over automation
- Enable seamless transitions between levels of automation
- Provide exploratory tools for situational and mutual awareness
- Support in-context and reliable revision of automation plans
- Consider human and automation limitations for operational safety

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Real time validation

Real time validation

For the specific case of these real time simulation we used a fake AI mode.

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Real time validation - LINK

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Validation results

- WP5 Validation results

ASTAIR Validation Activities

Initial assessment and review of expectations – ENAC

Paris CDG Workshop: Dec 2023

Fraport Airport Workshop: Apr 2024

Expert Group Workshop: May 2024

FTS – TUD

MAS Algorithm

RTS – ENAC
Mid May 2025

ATCO as a primary user; Operational feasibility, human factors

Final Workshop – DBL
End of May 2025

KPI conclusions & Recommendations

- Human Performance: HMI, teamwork, comms, etc.)
- Safety
- Liability
- AI: trustworthiness; human-AI collaboration
- Operational feasibility

Dec 2023

May 2025

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OBJ1: Operational Feasibility

R&I Need: Adapt intelligent systems to operators' mode of operations

Pilots (CRT-01.01)

The concept is promising, especially with datalink integration. However, full feasibility requires future direct pilot-in-the-loop validation.

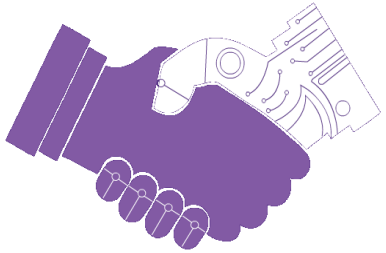
ATCOs (CRT-01.02)

Automation tools were found to be useful and operationally feasible. Refinements are needed for HMI design and handling unexpected events.

Ground Ops (CRT-01.03)

Lower automation levels are feasible and helpful. Higher automation needs more study, but high potential for integration (e.g., Tug Fleet Manager) was confirmed.

OBJ2: Human-Machine Collaboration



Objective: To evaluate the collaboration between human-controlled and automated processes/ AI.

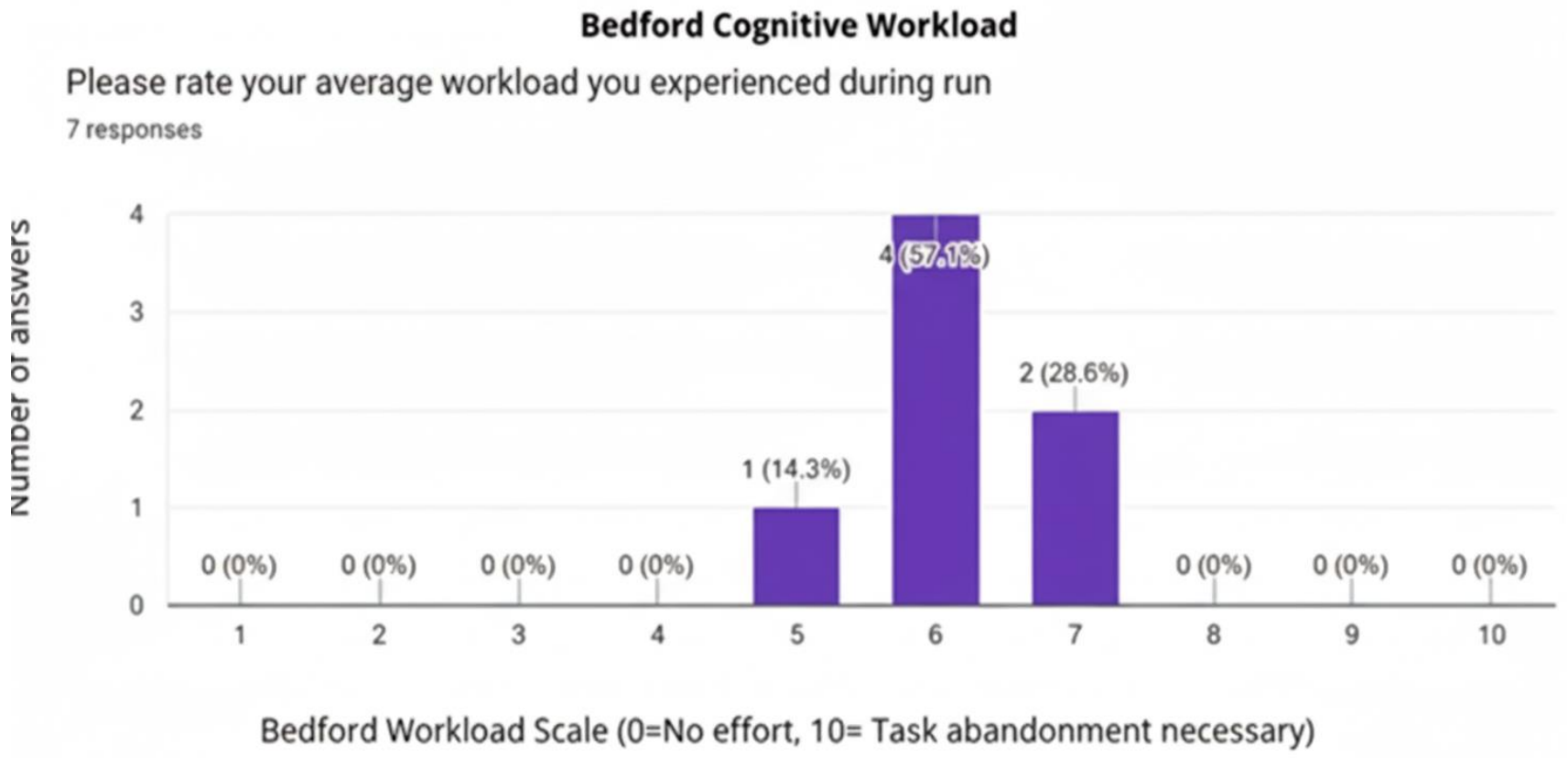
Criteria: Teamwork, workload, task distribution, logical consistency, liability

Human-AI collaboration was effective, with most operators reporting a **tolerable cognitive workload** (Bedford Score 6).

While **teamwork was good**, AI decision priority was sometimes unclear, and liability analysis highlighted **the need for transparent AI rationale** and clear tasks.

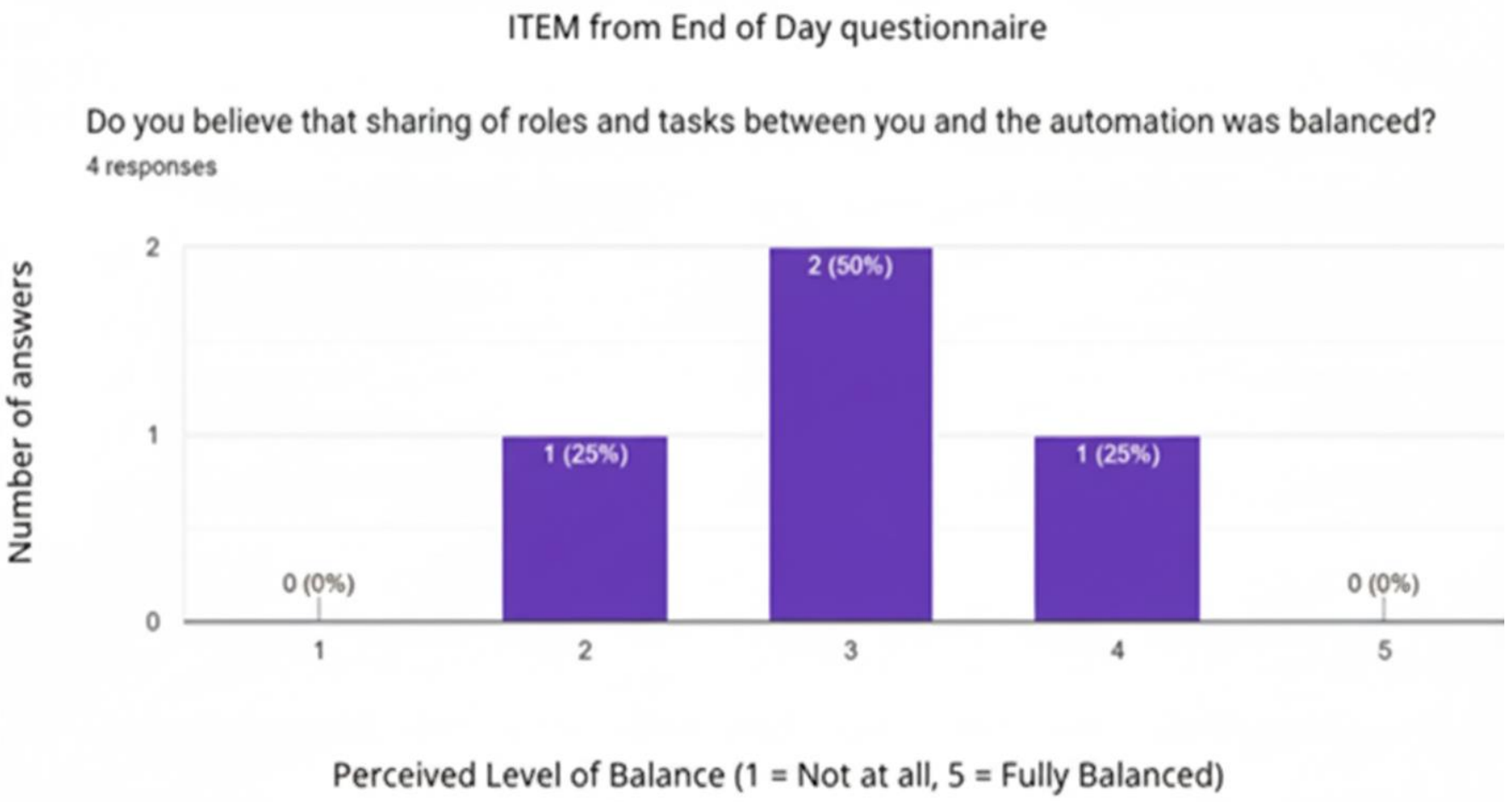
OBJ2: Human-Machine Collaboration

Degree of Collaboration - **Teamwork:** Measure the effectiveness of interaction between human operators and the automated system during taxi management tasks based on the operators' feedback.



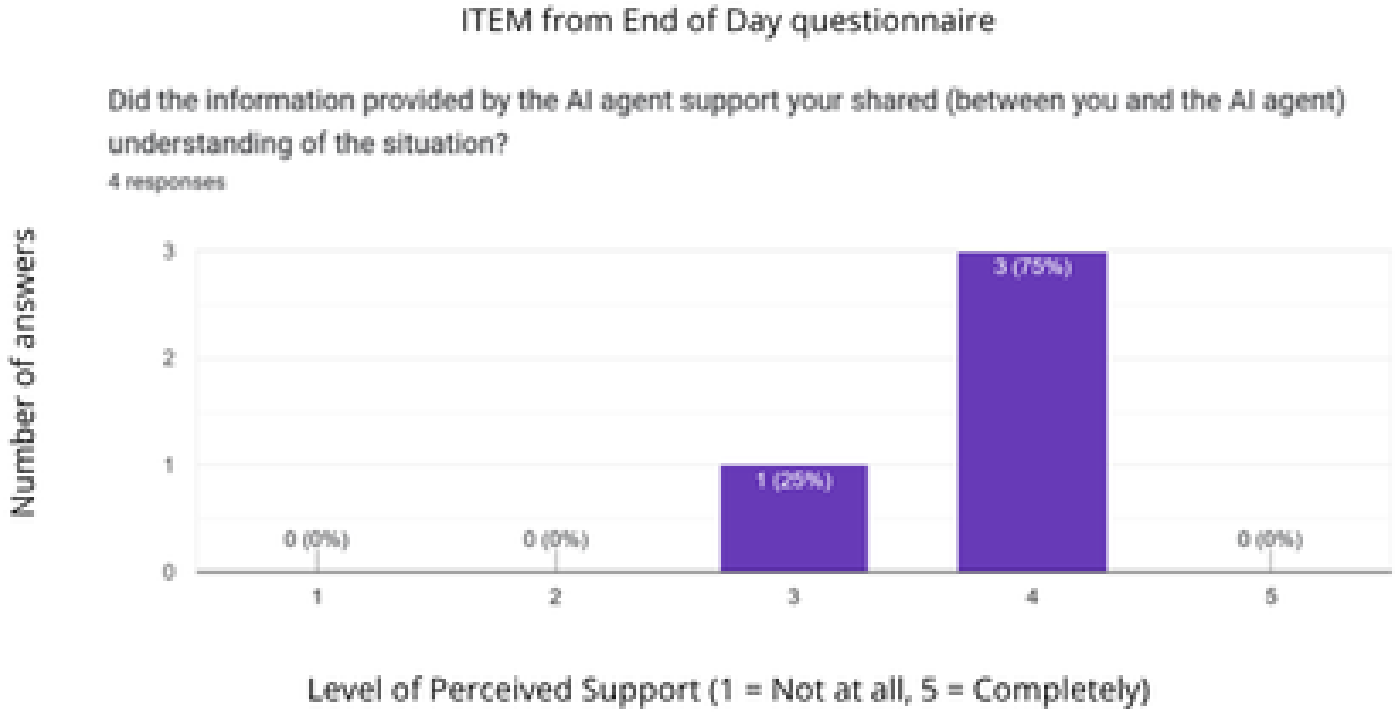
OBJ2: Human-Machine Collaboration

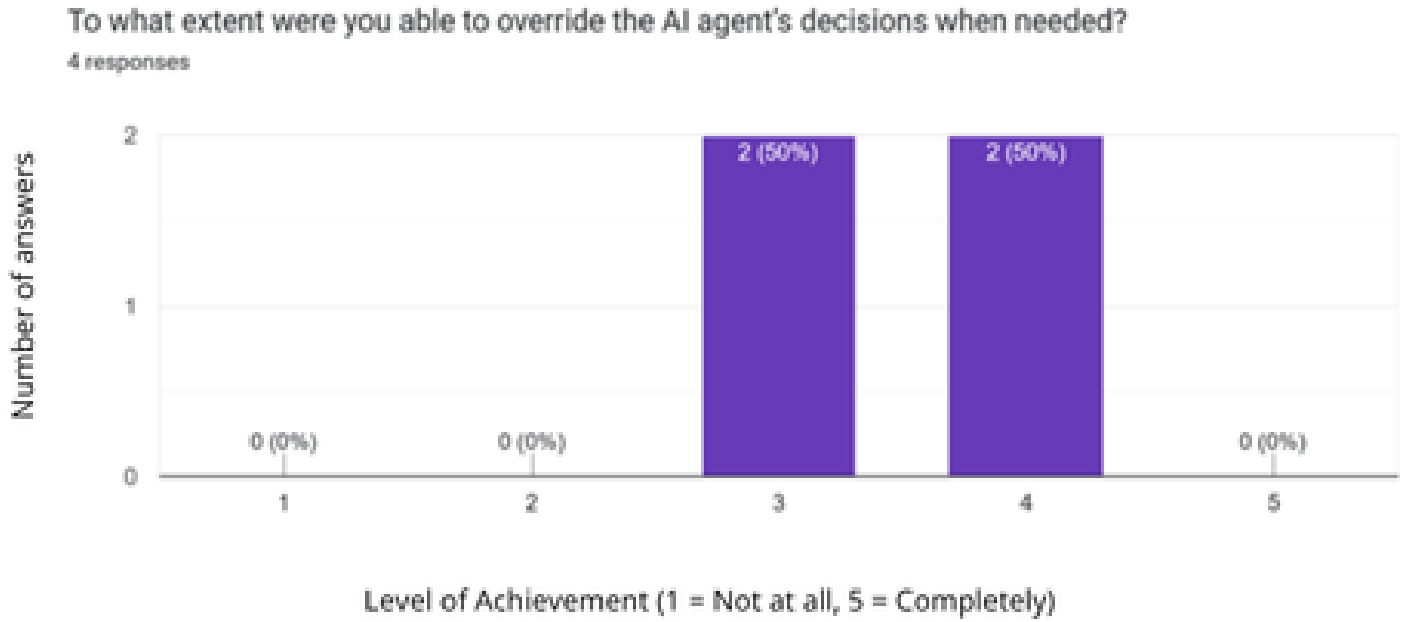
Integration Flexibility - **Task distribution:** Assess the system's ability to accommodate diverse **operator preferences and operational requirements** through flexible integration options based on the operators' feedback.



OBJ2

Assess that the **logical consistency across manual and automated control** is ensured based on the operators' feedback.





OBJ2 – Liability

Assess the Liability impact of innovations.

The liability assessment has been performed using the **Legal Case Methodology**, with the support the **Liability Tool, a proprietary asset of Deep Blue**.
This evaluation builds on the outcomes of the human factor analysis and **draws from the descriptions of the UCs** covered by the validation activities.

Risk / Scenario	UC1.a	UC1.b	UC2	UC3	UC4	UC5	UC8	Tot.
New tasks	15	12	11	13	9	7	5	72
Revised tasks	2	0	1	0	0	7	1	11
Current tasks	2	5	4	7	2	0	4	24
Causal dependencies	15	11	10	4	5	13	10	68
Analysed situations	36	25	32	19	15	28	15	170
Potential liability risks	11	12	13	15a	6	15	7	79

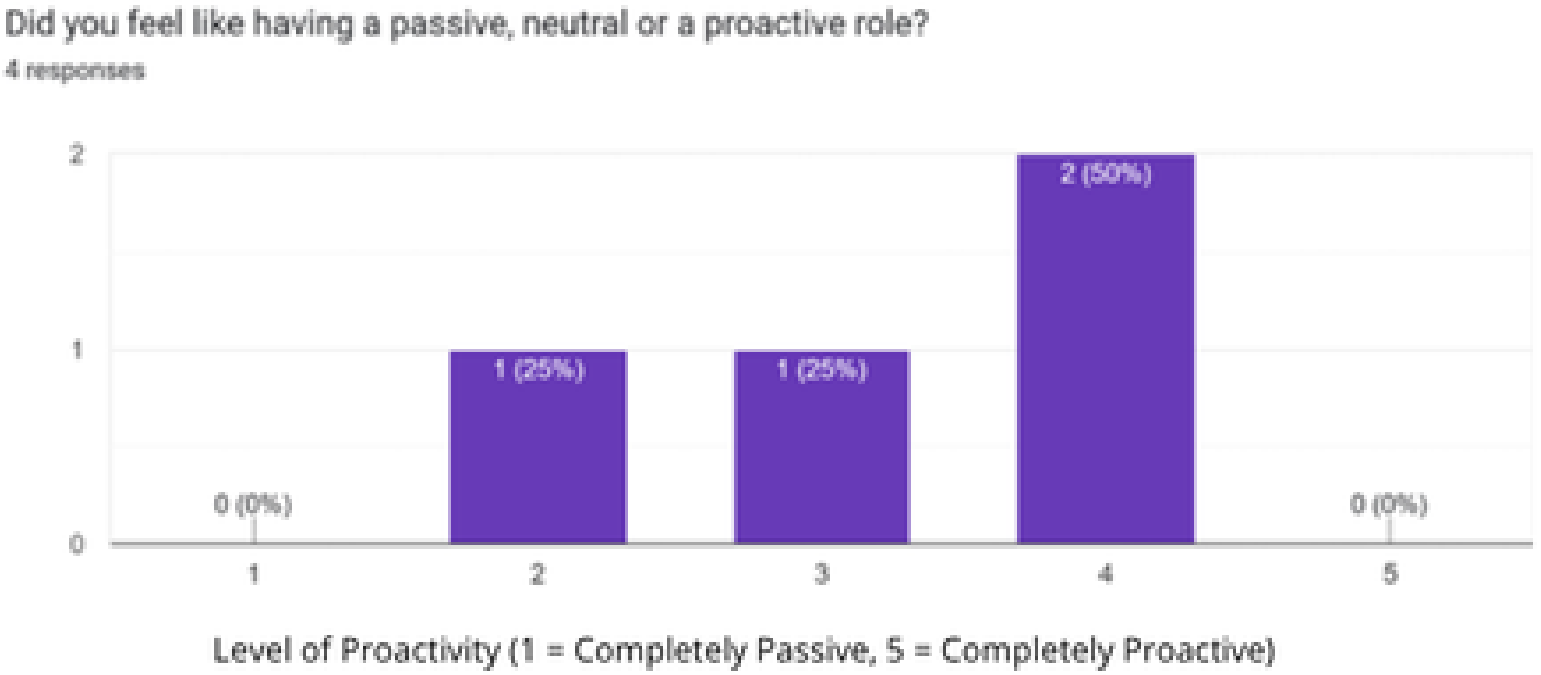
Overview of possible liability risks related to the ASTAIR ConOps

Also analysis per stakeholder: ATCO, TFM, pilot.

<u>Risks mitigations:</u>
Through design, organizational, and policy measures.
By improvement of the AI transparency, clarification of the legal status of the TFM (preferably as an ATCO-equivalent figure to better allocate responsibility), and strengthen operational procedures to support human oversight and accountability.

OBJ3: Interaction with different automation levels

Conclusions: Operators showed a high level of engagement and a positive attitude towards the system.
Half of the participants (50%) felt they had a **proactive role in managing the automation**.
Customisation options were present but had limitations, which is consistent with a TRL1 concept.

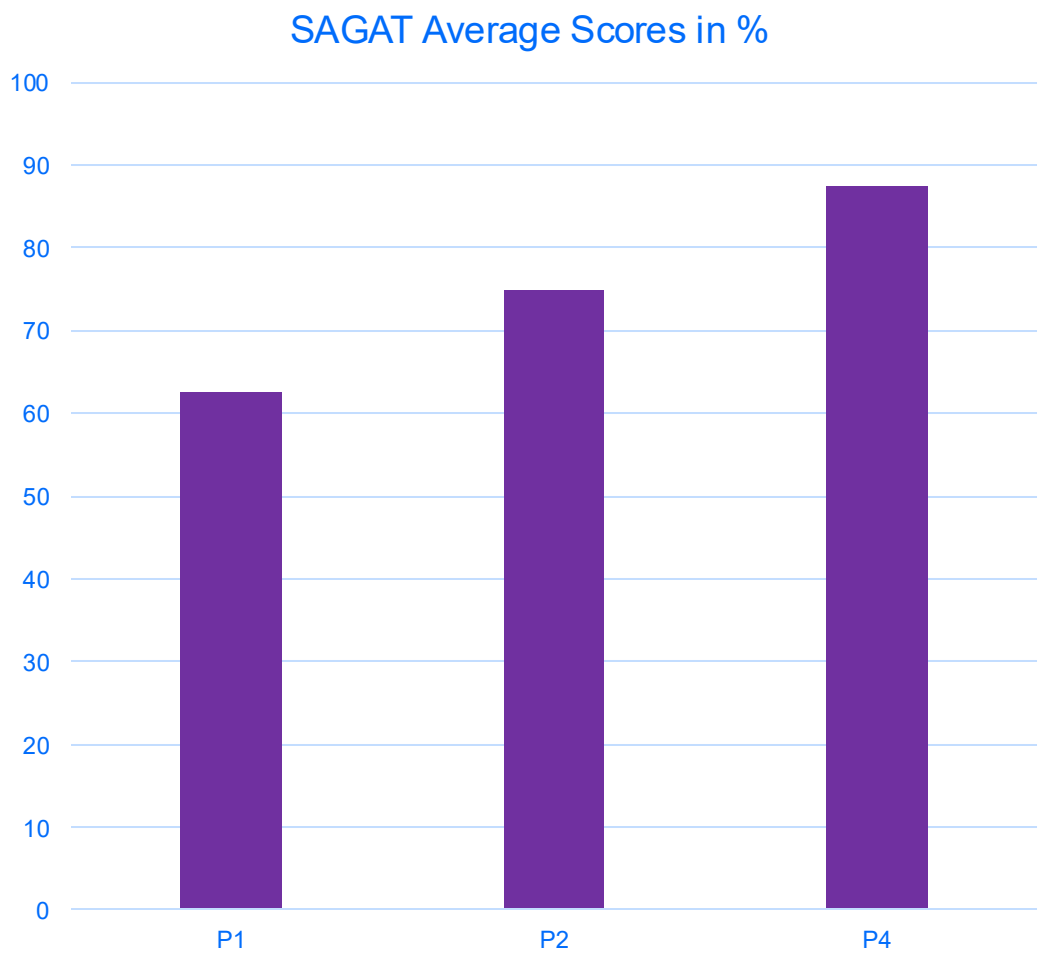


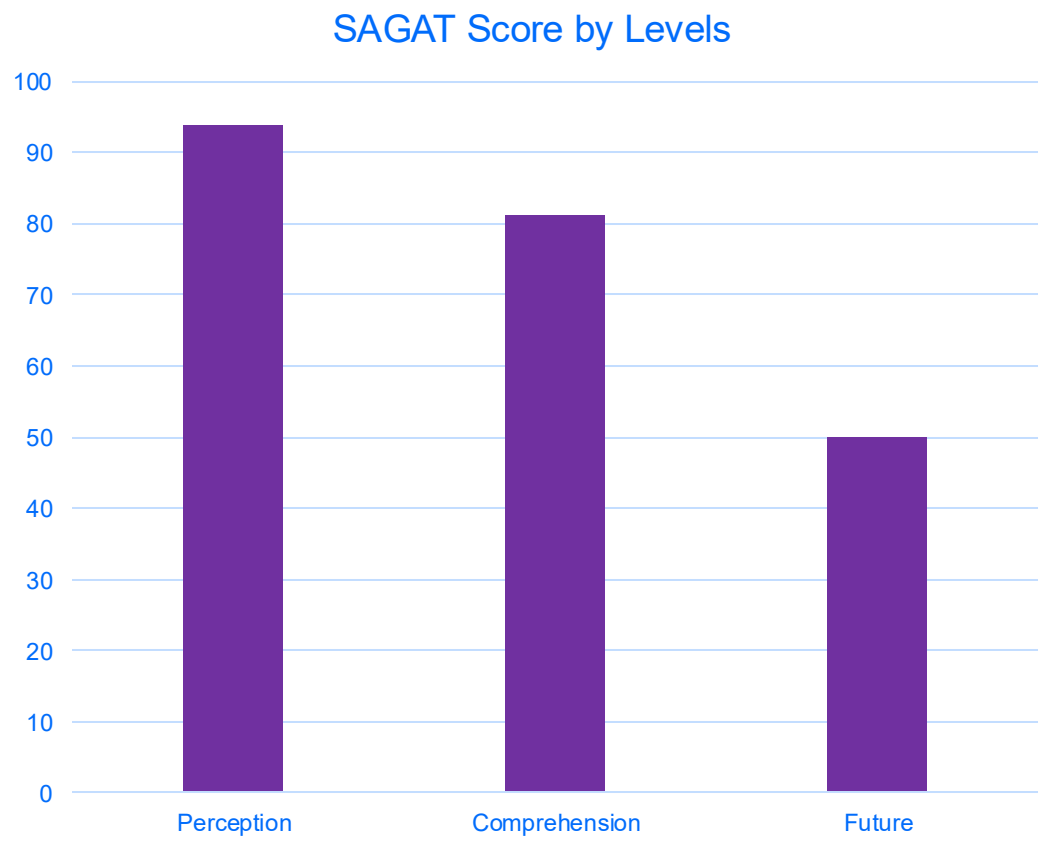
Adaptive Automation Level: the tools and relevant procedures and information flows varied in automation level depending on the situation, as described in the Use Cases in Concept Outline document. The automation levels varied from **1A to 3A.**

OBJ4: Usable HMI and Interactive Tools

Conclusions: HMI usability was "marginal" (SUS Score: 62.5), as expected at TRL1.
However, the tools strongly supported Situational Awareness for
Perception (88%) and Comprehension (81%). Awareness of Future events (50%) was lower,
indicating the Inspection interface needs improvement.

OBJ4: Usable HMI and Interactive Tools





SAGAT score by situation awareness level

OBJ5: Optimised Path & Motion Planning

Objective: Assess the Optimized Path & Motion Planning for Efficient Ground Operations.

Criteria: Capacity, Conflict-free routing, tugs resource management

Fast-time simulations at Schiphol showed that the ASTAIR system **maintains or improves runway capacity and reduces taxi times** compared to historic data. It also enhances slot compliance and optimizes runway usage during peak periods.

Fast-time simulations showed the routing algorithm effectively produces **conflict-free trajectories.**

Simulations show that increasing the number of Electric Towing Vehicles (ETVs) **reduces total fuel consumption of outbound taxiing aircraft** by **up to 38%** for RMO North **and 28%** for RMO South, with diminishing returns beyond certain fleet sizes.

ASTAIR SESAR Solution and maturity gate results

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SESAR Solution 0501 – TRL 1 Maturity concerns

Several limitations remain, as expected at this maturity stage:

- The integration of the algorithmic modules with the main HMI was not fully demonstrated during validation, due to technical and scheduling constraints.
- Mix mode of automated and manual traffic have not been researched thoroughly (i.e. when the ATCO needs to handle an unexpected event manually while AI recomputes a solution.)
- Certain stakeholders, in particular pilots and airlines, were not fully involved in the RTS.

SESAR Solution 0501 – TRL 2 Maturity concerns

- Architecture integration has not been studied, even though a workshop with stakeholders and experts discussed operational feasibility.
- A formal Human Performance with TRL2 criteria shall be performed, only TRL1 objectives have been actually evaluated although real time simulations were conducted.
- RTS including a tower controller and AMAN/ DMAN

SESAR Solution 0501 – Project recommendations

- **Validation**
  - **Key Technologies**: Testing the feasibility of proposed autonomous taxiing solutions (e.g., tugs, onboard systems) under operational conditions.
  - **Other end users / effected stakeholders' involvement in the validations (RTS and workshops)**, such as pilots, tug fleet manager, airlines, tower controller.
- **Integration with Existing Systems**: Continuing the development of integration between ASTAIR and current airport systems such as A-CDM and A-SMGCS to ensure seamless operations. Better integration of inspecting tools into existing A-SMGCS.

SESAR Solution 0501 – Project recommendations

- **Human-Automation Teaming**:
  - Exploring advanced collaboration.
  - Handover when automation fails, i.e. degraded automation (keep lower level of automation (L1A-L2A) + recommendation tools).
  - Faster computation times exploring mixed AI such as surrogate.
  - Using machine learning based AI to facilitate the integration of ASTAIR AI.
- **Operational and Safety Enhancements**: Refining conflict resolution mechanisms and safety nets for ground controllers to handle non-nominal situations effectively.
- **Liability:** EASA classification of Level 2 AI applications gives some guidelines for development, ASTAIR could be an interesting basis to look into Level 2A and 2B development requirements.

SESAR Solution 0501 – Project conclusions

- The validation confirmed the initial feasibility of the ASTAIR concept in supporting the automation of airport ground operations. **While some success criteria were partially OK (POK), this is mainly due to the current maturity level (TRL1)**, all **validation objectives are considered achieved - OK.**

- TRL 2 assessment has been partially achieved, no major blockers showed but further evaluation shall be made.

ASTAIR

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