A mesterséges intelligencia bevezetésének lehetősége a légiforgalmi irányításban – az AWARE projekt eredményei

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- **IX. Magyar Közlekedési Konferencia – 50. Útügyi Napok**

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EUROPEAN PARTNERSHIP

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Project consortium

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TERN SYSTEMS

IFATCA

Zurich University of Applied Sciences

zh aw School of Engineering

ZAV Center for Aviation

JKU JOHANNES KEPLER UNIVERSITÄT LINZ

UNIVERSIDAD POLITÉCNICA DE MADRID

POLITÉCNICA



LFV AIR NAVIGATION SERVICES OF SWEDEN

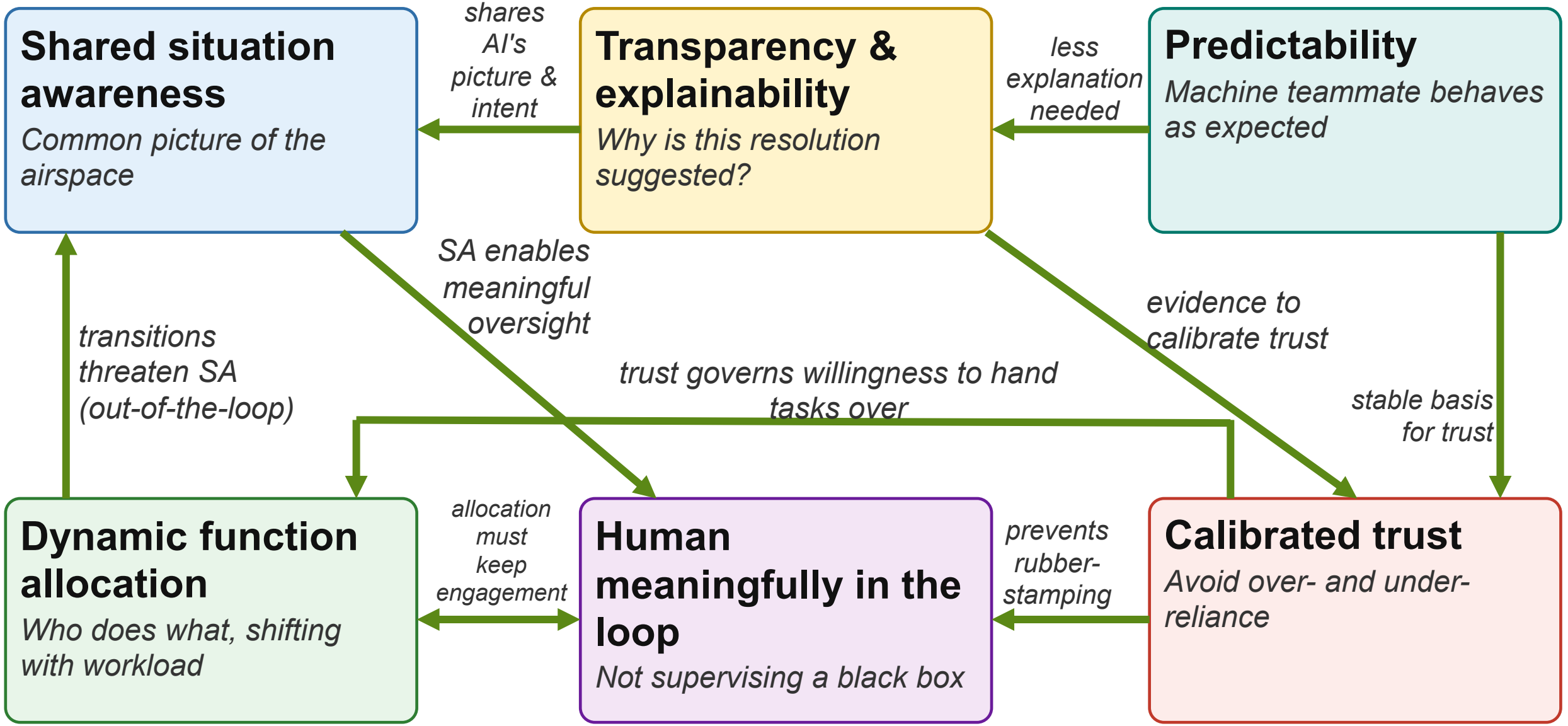
УКРАЕРОРУХ UkSATSE

Slot consulting

University of Zagreb Faculty of Transport and Traffic Sciences

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Core Concepts of Human-AI Teaming in Air Traffic Control



Project objectives

GENERAL OBJECTIVE

Develop an AI assistant application that supports ATC operations, built on an enhanced artificial situational awareness (ASA) solution.

SO1

Intent-aware situational awareness

Extend the ASA system with methods that assess the ATCO's intent and goals from gaze, HMI interactions and the traffic context.

SO2

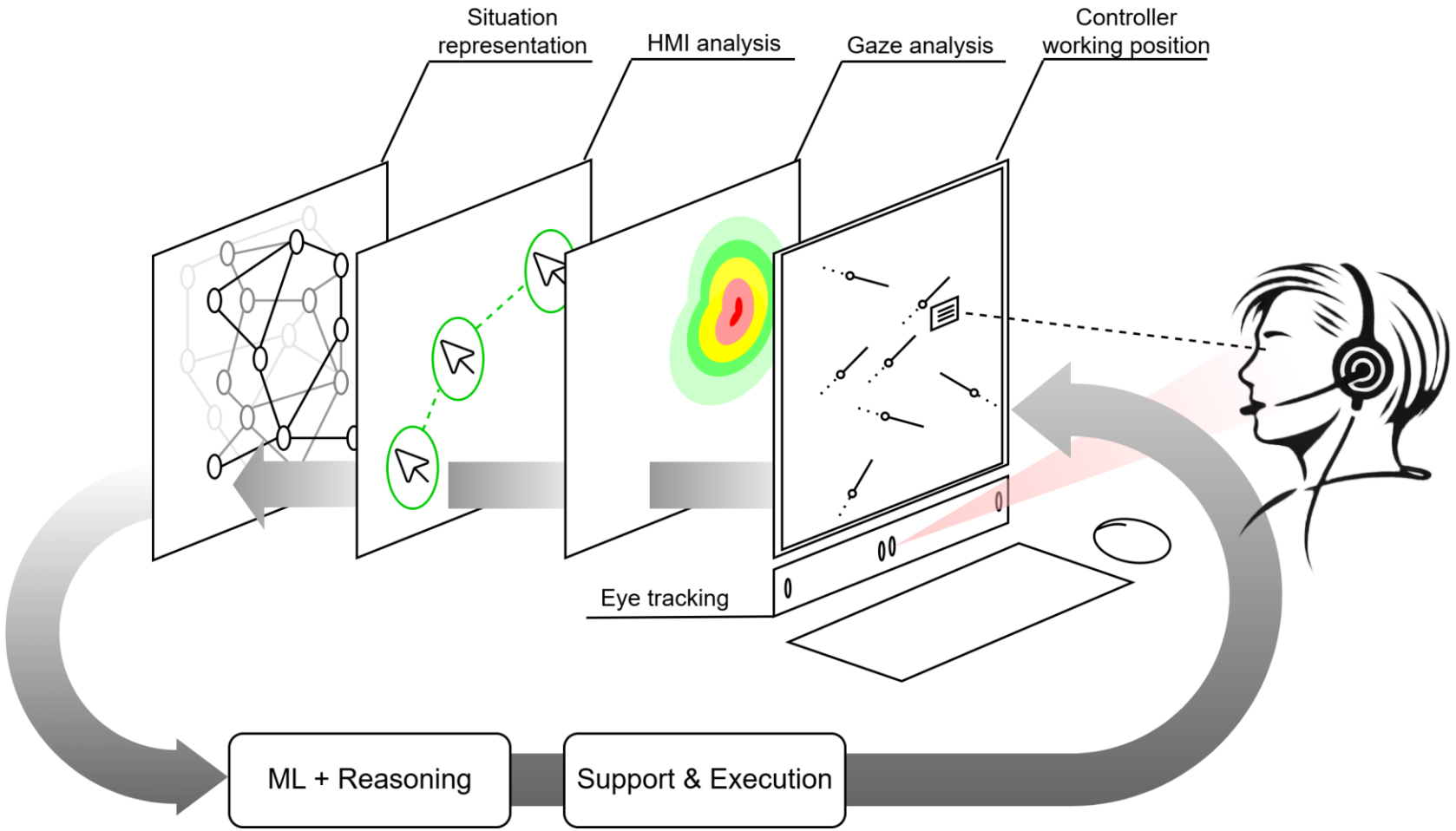
Adaptable support actions

Develop a method for adaptable selection and implementation of support actions using ML and non-ML tools, from advice (EASA Level 2A) to execution (Level 2B).

Concept – closing the loop

Creating an effective team in collaborative environment requires understanding other team member's states, including their goals, needs and intent.

AWARE achieves this by tracking ATCO's human-machine interactions and gaze, putting them into the context of the current traffic situation and environment.



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Methodology



Concept definition

ConOps, OSED and FRD; HP, safety, security and environmental assessments

Data collection

Zagreb: 23 UkSATSE ATCOs, three 1-h scenarios; eye tracking + HMI logs; ATCOs self-annotate their tasks

Development

Knowledge graph & reasoning, four ATCO tools, intent model, AWARE HMI in Polaris ATM

Workshop

Malmö: 9 ATCOs try advisory & execution modes; HMI and output strategy refined

HITL simulations

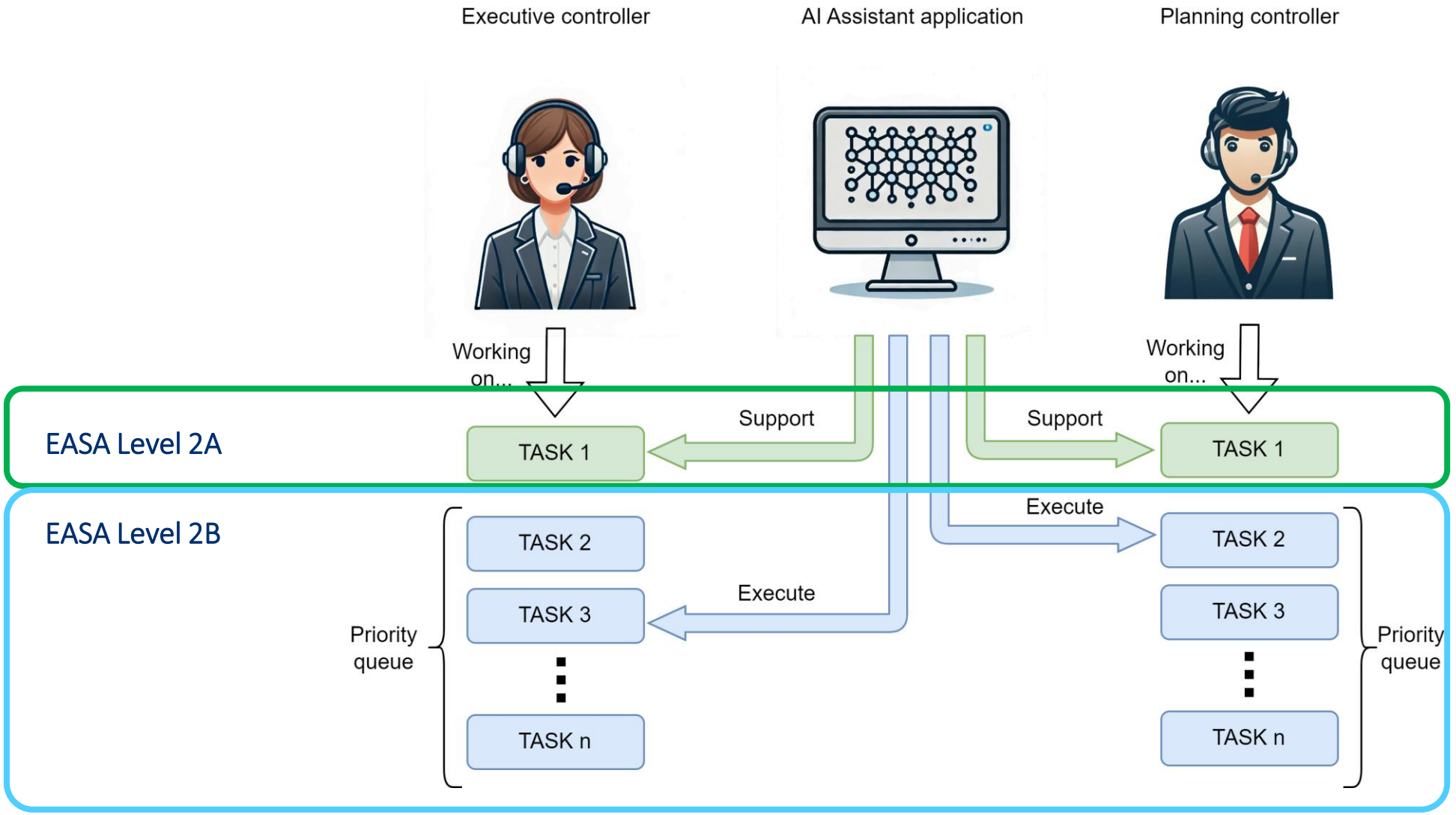
Malmö ACC: 16 ATCOs, 4 exercises × 4 support conditions

Maturity assessment

Exploratory Research Report: KPA results, recommendations, TRL2 exit

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Levels of Assistance



Level 2A – Advisory

AI supports the task the ATCO is working on; the ATCO decides and acts.

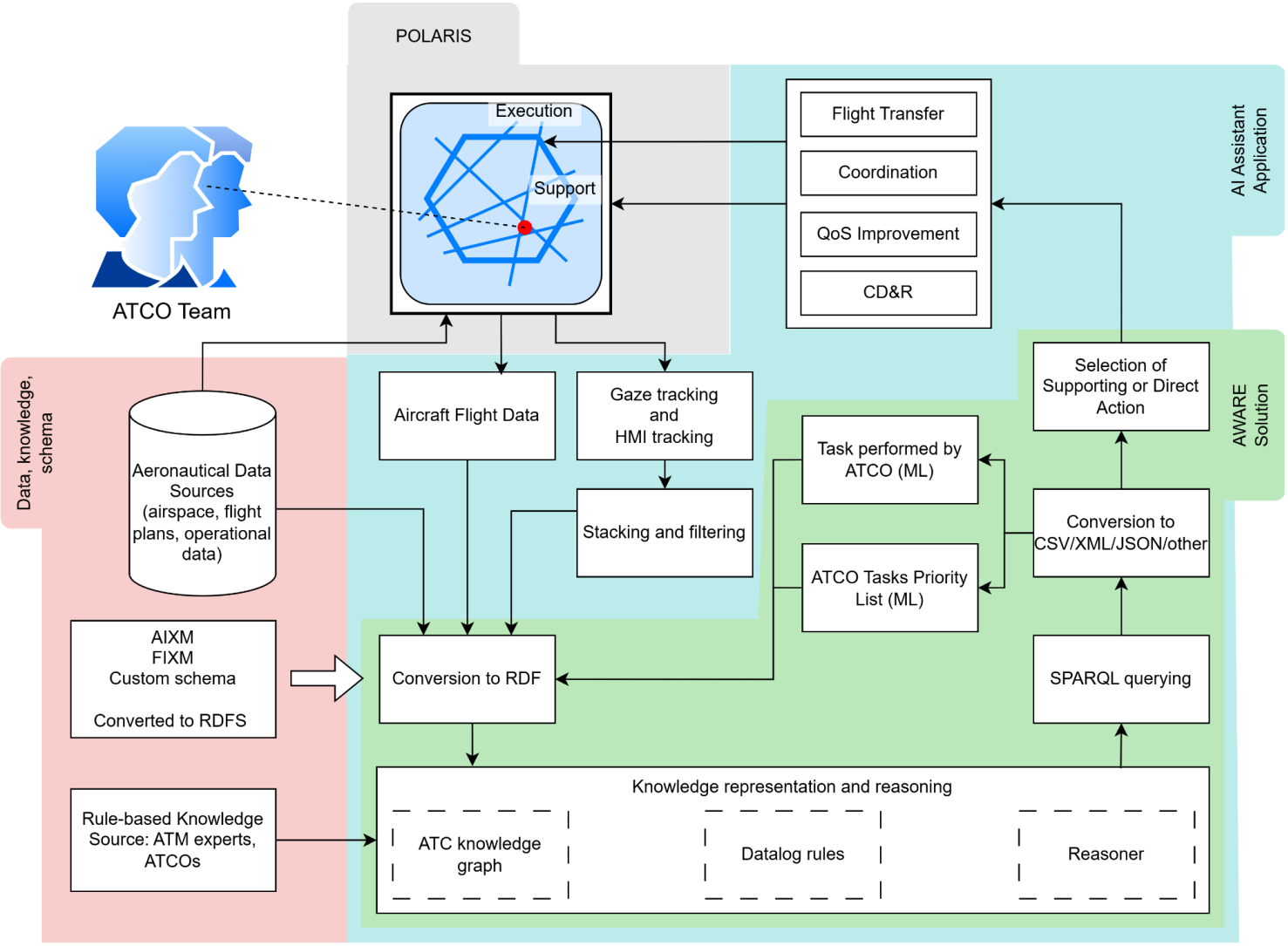
Level 2B – Execution

AI executes queued routine tasks after 30 s unless the ATCO dismisses them.

The ATCO can interrupt or override any action at any time.

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System architecture



Polaris ATM

ASD for ATCO interaction; FDP with 4D trajectory prediction, safety nets; Orion traffic simulator

Data, knowledge & schema

AIXM / FIXM + custom schema as RDFS; rule-based knowledge elicited from ATCOs and ATM experts

AWARE solution

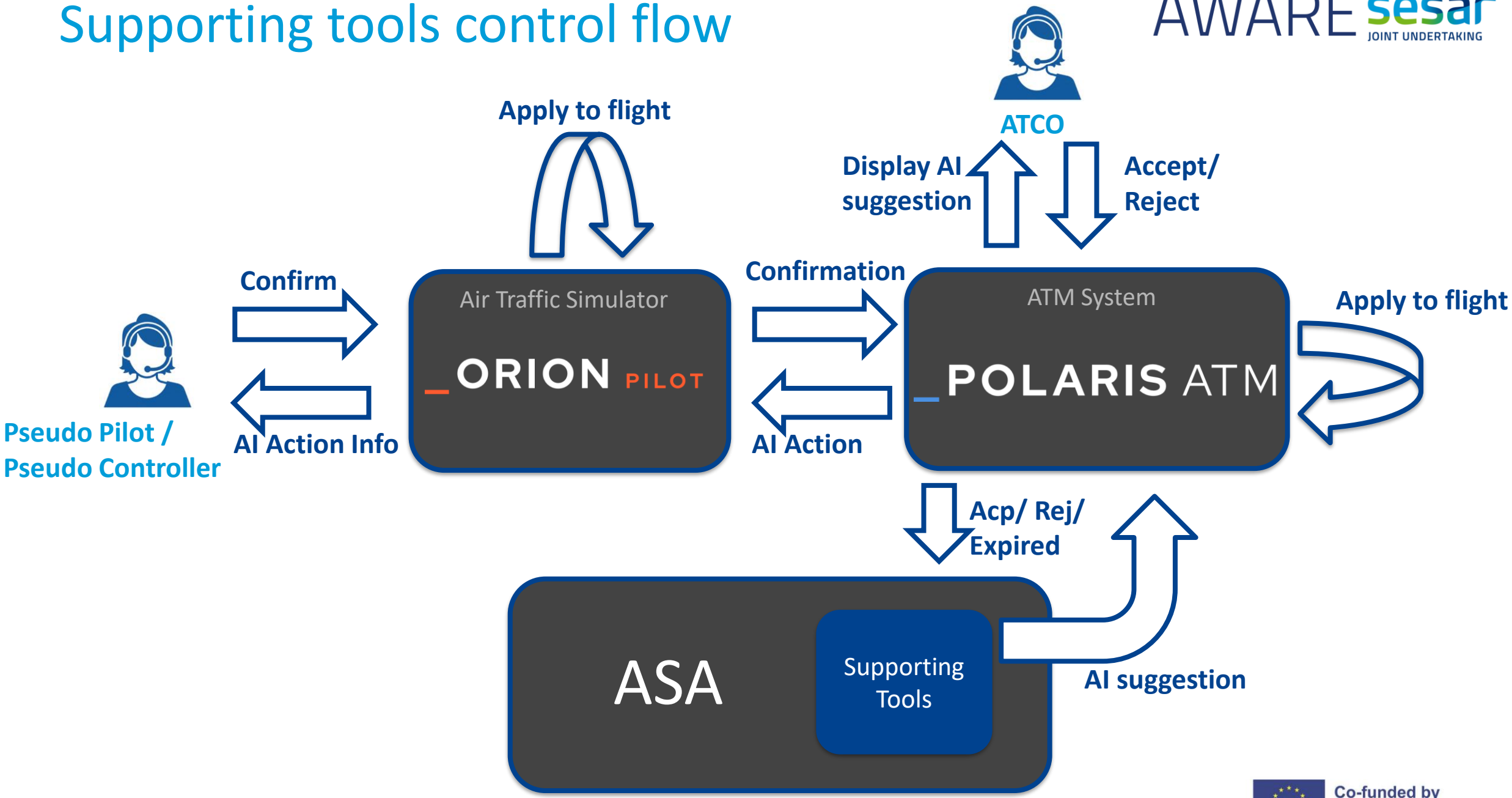
RDF knowledge graph + Datalog rules + reasoner; ML task inference and priority list; selection of support or direct action

AI Assistant Application

Four ATCO tools (transfer, coordination, QoS, CD&R) return advisory or execution actions to the ASD

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Supporting tools control flow



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Backend – knowledge graph & reasoning

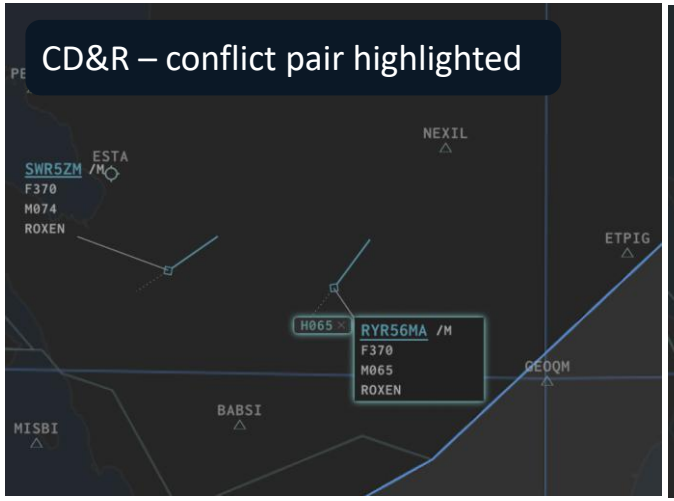
1. **Ingest**
   AIXM airspace, FIXM flight plans, surveillance tracks, 4D trajectories from Polaris, gaze and HMI events
2. **Represent**
   Converted to RDF in an ATC knowledge graph; each time-stamp kept in its own named graph (rolling window)
3. **Reason**
   Datalog rules derive new facts: distances, predicted positions, conflict candidates, transfer and coordination conditions, etc
4. **Serve**
   ATCO tools and ML modules query the graph (SPARQL); their outputs flow back as new facts

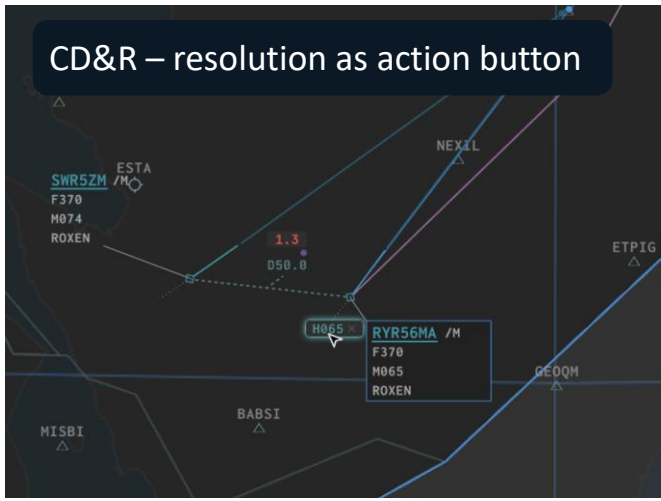
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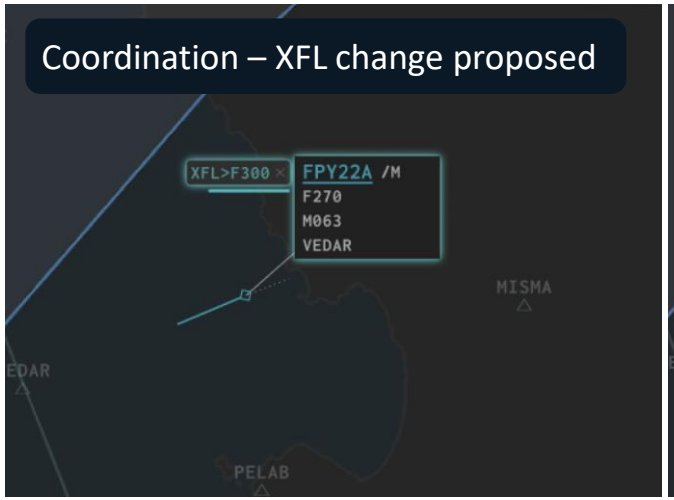
Frontend – AWARE HMI in the Polaris ASD

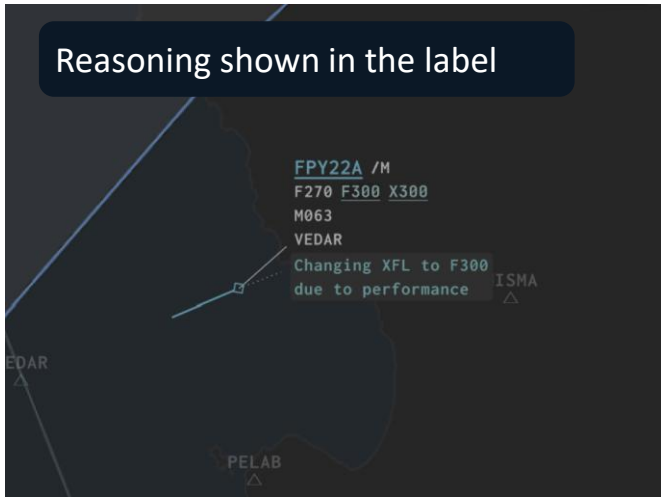
One design language for every AI suggestion

- **AI Glow,** soft outline on each track label the AI is acting on
- **Action button** left of the label: the suggestion plus ✕ to dismiss
- **Advisory:** ATCO accepts; the suggestion expires after 30 s
- **Execution:** countdown bar, executed automatically unless dismissed
- **Context on demand:** hover shows the proposed route or conflict geometry; free-text reasoning in the label (not completely implemented)









Prototyped in Figma, refined with ATCOs in an HMI design workshop

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Controller tools

Conflict detection & resolution

- Detects pairs predicted to infringe separation on 4D trajectories
- Proposes FL change, direct-to (with checking for new conflicts)
- Advisory from 10 min to CPA and execution from 5 min as a safety layer

Transfer

- Watches flights approaching the sector exit
- Transfers only if clean, assumed, LoA-compliant, route unchanged and not in a conflict
- Otherwise hands over to the Coordination tool

Coordination

- Finds flights needing coordination before transfer or due to entry conflicts
- Inbound RTI, RRQ, outbound RRV, REV, TIP (OLDI messages)
- Triggered by CD&R, QoS, Transfer tool or the ATCO

Quality of service

- Direct routings and continuous climbs to the requested FL; pilot requests
- Checks LoA, traffic conflicts and TRA crossings
- e.g. offers DCT as soon as a military area is deactivated

Same functions in both modes: execution after 30 s unless dismissed, max. 5 outputs shown, priority conflict > coordination > transfer > QoS, repeated rejection suppresses same-type actions

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Experiment – validation campaign

Malmö ACC
sector ESMM 23

13–24 April 2026
two-week campaign

16 ATCOs
LFV 6, UkSATSE 7, IFATCA 3

Polaris + Orion
integrated with the ASA system

Exercise	Focus	Complexity	Flights/h
TVAL.01.1	Workshop – qualitative feedback	-	-
TVAL.02.1	Nominal en-route traffic	Medium	53
TVAL.02.2	Conflict detection & resolution	High	63
TVAL.02.3	Military restricted areas (TRA)	High	69
TVAL.02.4	Future traffic, +25 % peak occupancy	Very high	75

Four support conditions per exercise

No support
Baseline – current operations

Advisory mode
EASA 2A – AI suggests, ATCO decides

Episodic execution
EASA 2B – AI executes after 30 s unless dismissed; one exercise per ATCO

Continuous execution
Same ATCOs in execution mode in all four exercises (familiarisation)

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Experimental setup

Simulation lab layout and session flow



Session flow

1. **Offline training**
   Completed by the ATCO before the lab session
2. **Initial briefing and questionnaire**
   HP expert, at the briefing table
3. **Biometrics**
   EEG headset and physiological sensors fitted to the ATCO
4. **Exercises**
   ATCO, pseudo-pilot and feeder on POLARIS + ORION, supported by the AI assistant application
5. **Post-exercise questionnaire**
   HP expert #2
6. **Annotation**
   ML expert, at the annotation workstation
7. **Final briefing**
   Back at the briefing table

- ATCO (study participant)
- Pseudo-pilot and feeder
- HP experts, ML expert, engineering team
- Engineering team area and support link

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Experiment – what we measured

Operational KPIs

- Safety occurrences SAF1.x
- Capacity CAP2, cost-efficiency CEF2
- Fuel burn & CO_2 (FEFF1, ENV1)

Subjective

- ISA workload every 5 min
- SA, stress, performance, human-AI alignment
- Questionnaires & debriefs

Physiological

- ECG & BVP (HR, LF/HF)
- Skin conductance, respiration, temperature
- HEG, pupil diameter

Eye tracking

- Fixations, scanning entropy
- Revisits, time since last fixation
- Time to identify conflict aircraft

HMI interaction

- ASA suggestions accepted / dismissed / expired
- Clearances, label & tool use
- Actions per aircraft

Analysis: descriptive statistics, linear mixed-effects models and Spearman correlations, 16 ATCOs × 4 exercises = 64 runs

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Results at a glance



Capacity Imposed demand of 53 → 75 flights/h handled, no isolated capacity gain	Met
Cost efficiency Follows capacity (flights per ATCO-hour)	Met
Safety Fewer safety events with ASA, lowest in episodic execution	Met
Environment CO_2 change < 0.3 % vs 5 % target, gains in TRA avoidance	Partially met
Operational efficiency Fuel burn per flight broadly stable	Partially met
Human performance Workload flat overall: lower in episodic, higher in continuous execution	Partially met

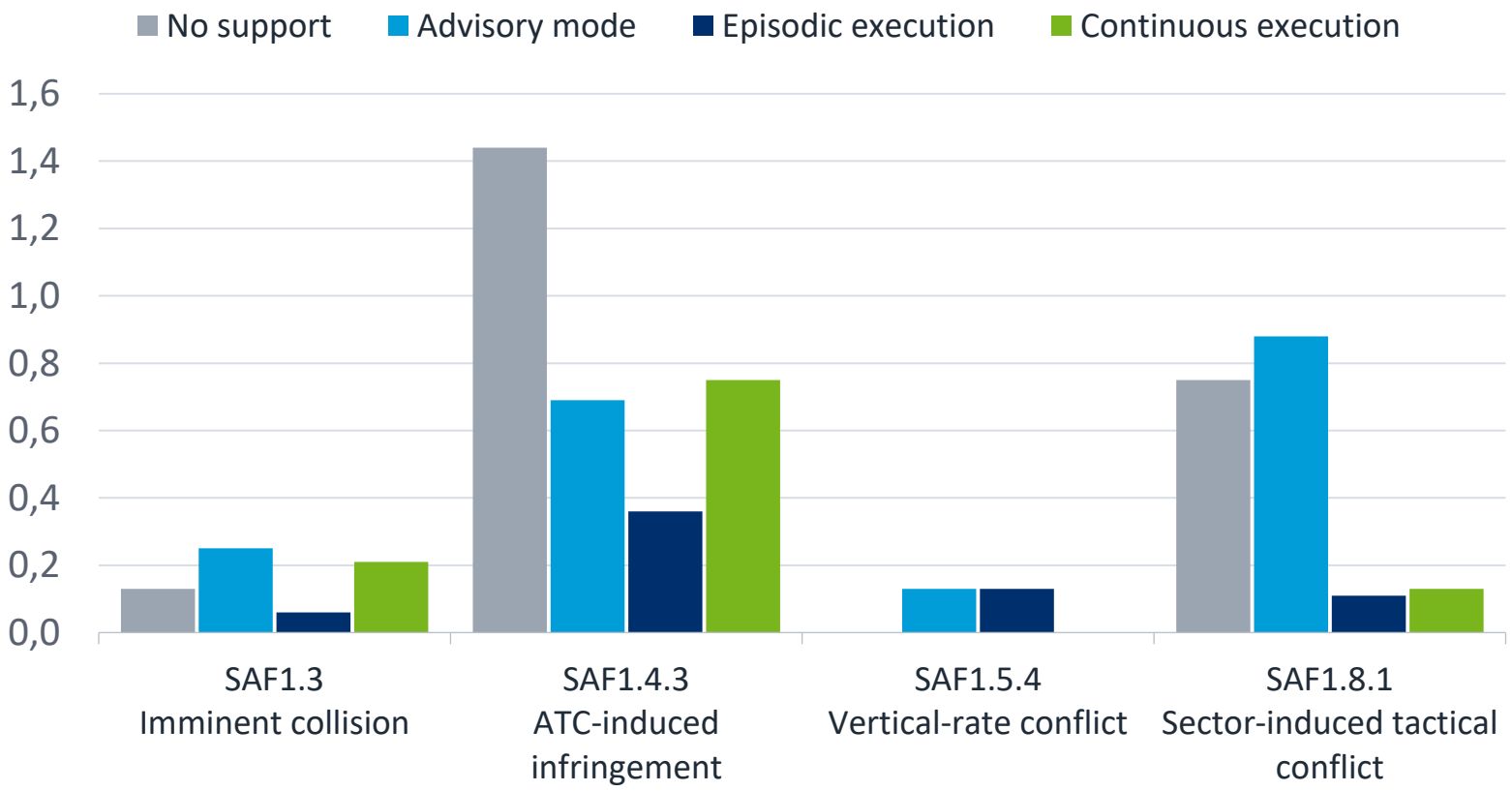
Sample size
+
No planner
+
New airspace
New ATM system
New ConOps

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Results – safety

Selected safety occurrences per run, by indicator and condition



4× fewer ATC-induced imminent infringements (SAF1.4.3): 1.44 → 0.36 per run, episodic execution vs no support

7× fewer sector-induced tactical conflicts (SAF1.8.1): 0.75 → 0.11 (episodic) and 0.13 (continuous)

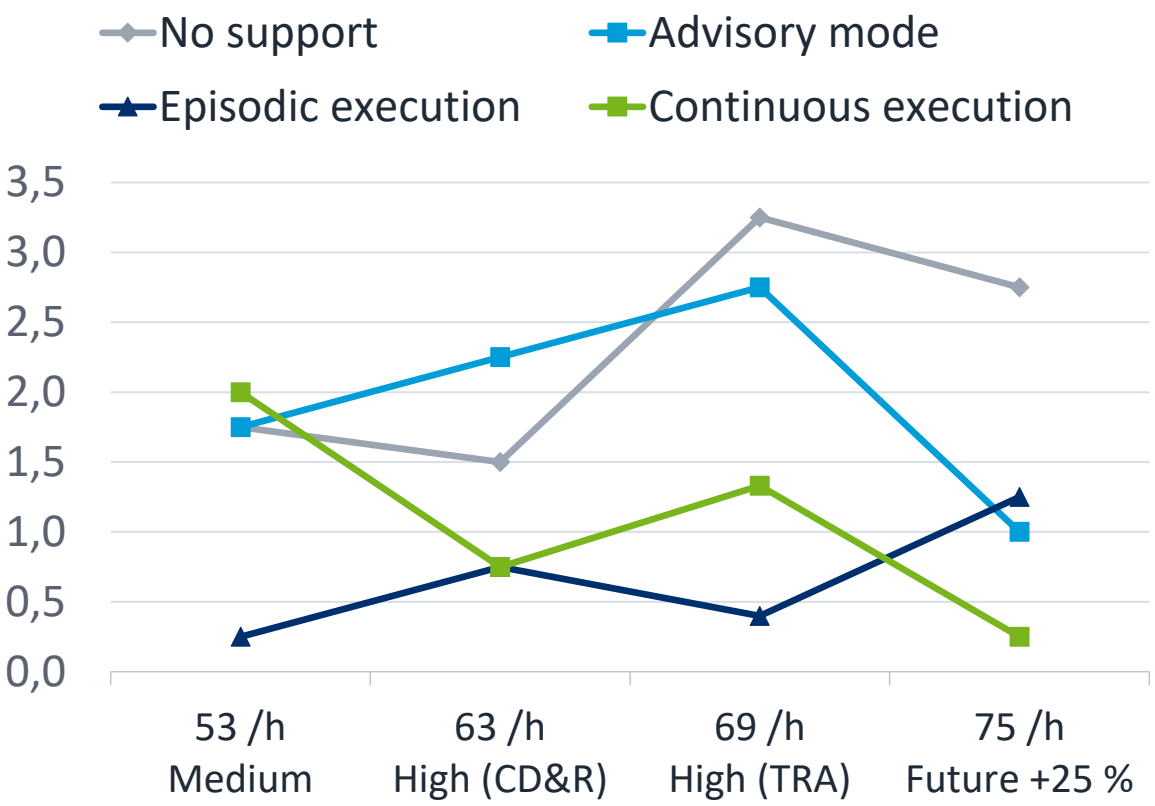
! SAF1.5.4 appeared only with ASA: BADA vs platform performance mismatch, an integration fix for TRL3

Level busts (SAF1.10.1) and speed deviations (SAF1.10.3) were injected SA probes without dedicated ASA support and are excluded.

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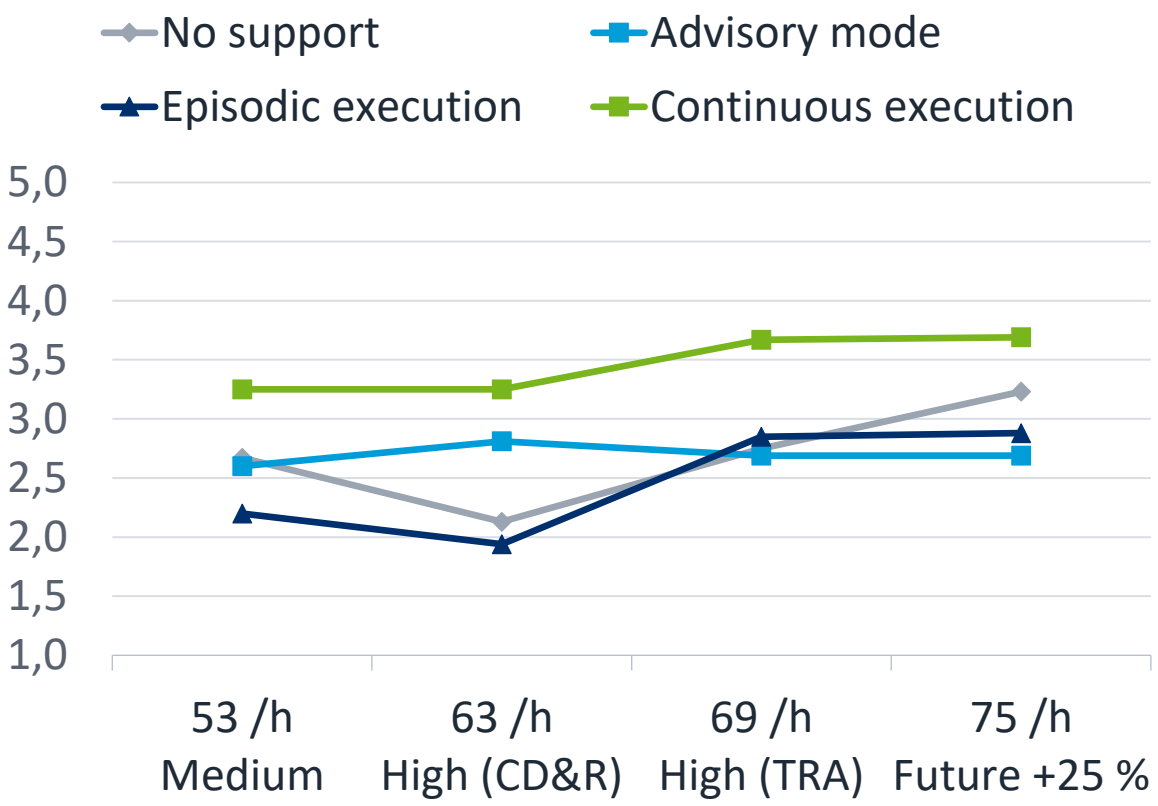
Results – traffic load, safety and workload

Selected safety occurrences per run



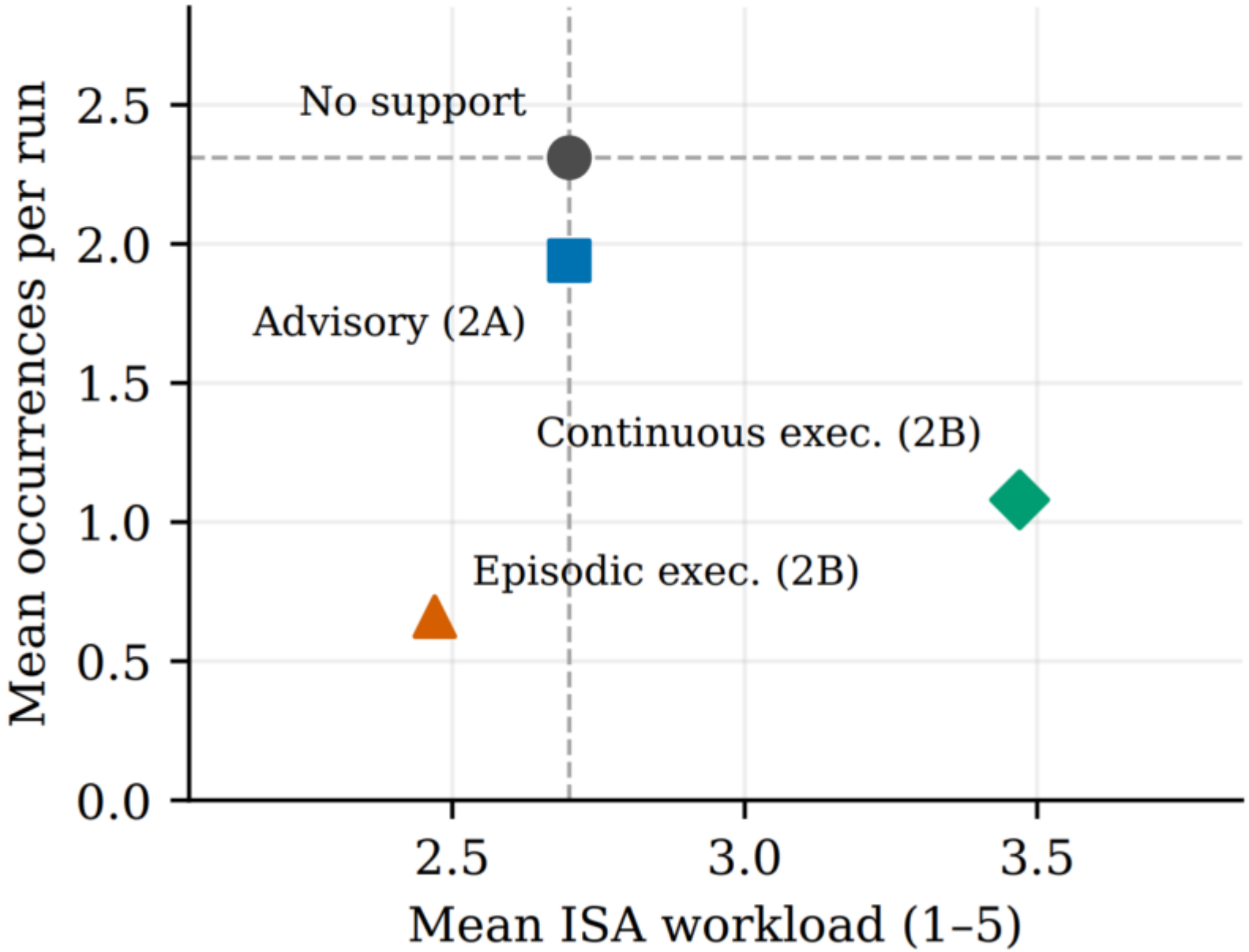
Subjective workload (ISA, 1–5)

mean per exercise



Mean ISA 2.70 none, 2.70 advisory, 2.47 episodic, 3.47 continuous; no significant effects (mixed model, all $p > 0.15$).

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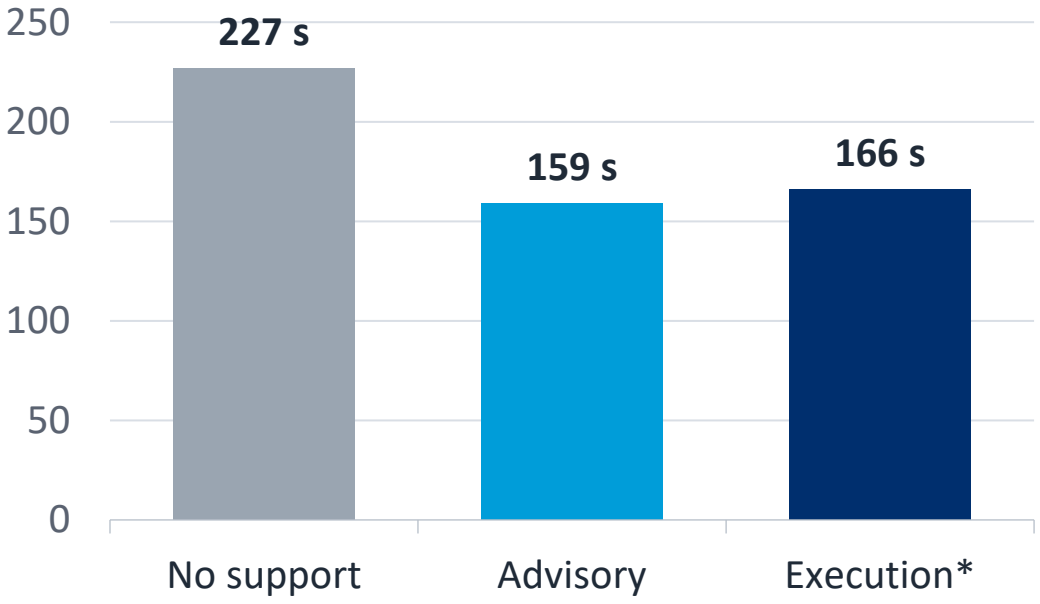


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Results – controller behaviour

Time until all conflict aircraft were fixated

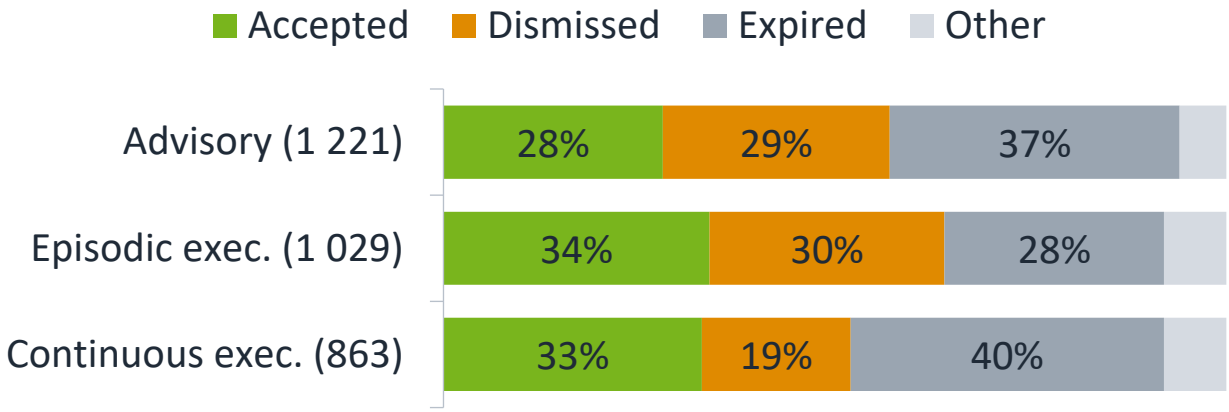
mean seconds per run, eye tracking



** Episodic and continuous execution combined. Exploratory descriptive statistics (64 runs); difference not significant (Mann-Whitney p = 0.27). Expired = no ATCO response before the timeout; in execution mode the action was then implemented.*

What happened to ASA suggestions

mean % of inputs per run, HMI logs



≈ 28 % faster visual identification of all conflict aircraft with ASA support

22 % of ASA suggestions concerned aircraft not fixated in the previous 60 s

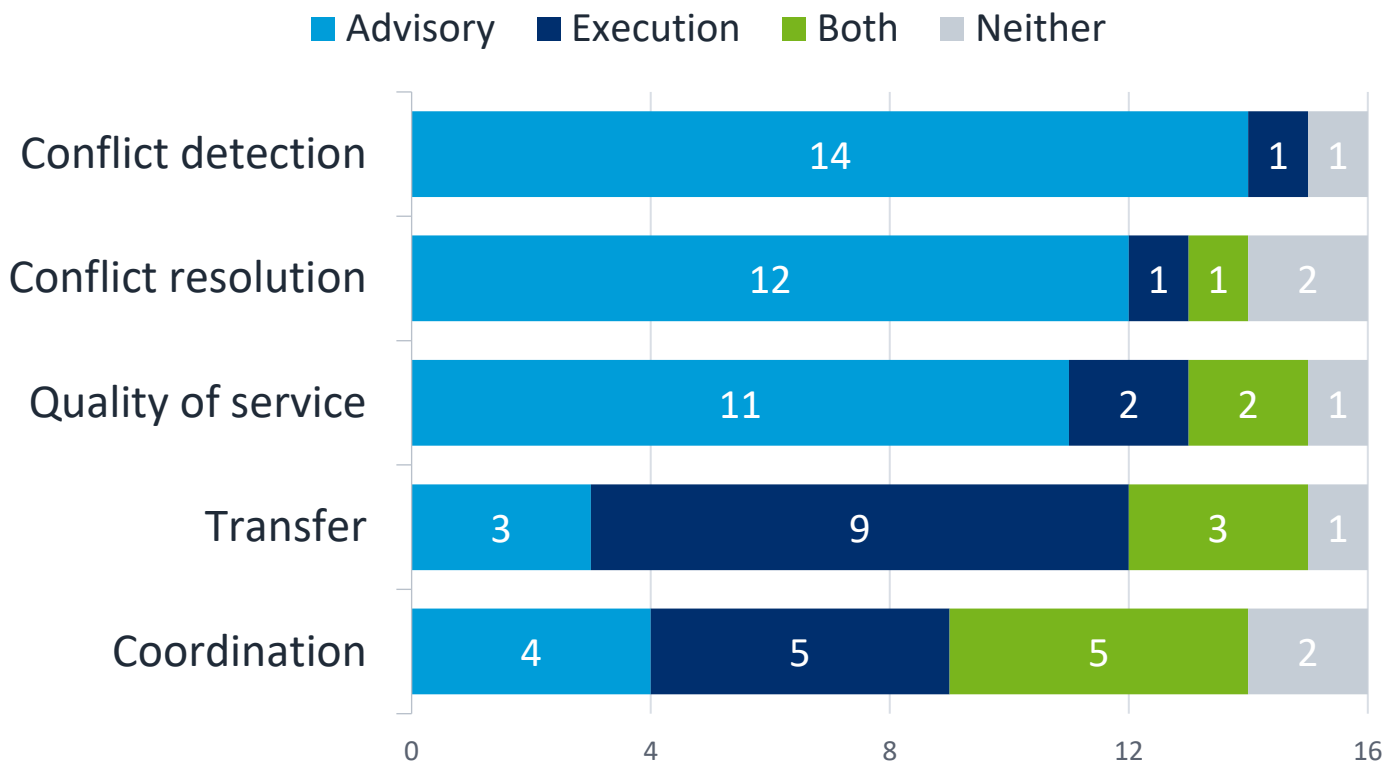
4.5 → 7.4 ATCO actions per aircraft without vs with ASA, **suggestions add interactions**

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Results, what the controllers told us

Preferred support mode per tool in high traffic

number of ATCOs (n = 16), post-campaign questionnaire



10 / 16 prefer advisory mode in general

61 % of suggestions: clear why the AI made them (mean)

4.6 / 5 confident overriding AI suggestions

2.8 / 5 able to intervene in execution mode when wanted

2.5 / 5 AI provides clear explanations for its advice

"When I vectored around a TRA, it advised me as soon as I could give DCT again."

— ATCO, HITL campaign

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Lessons learned

Timing

Too many simultaneous or premature suggestions (e.g. early transfers) distract. Group, filter, prioritise and deliver at natural decision points.

Explainability drives trust

ATCOs re-checked AI outputs, cancelling workload gains. Show the rationale, secondary conflicts and what the AI has already done.

Automate routine, advise on complex

Execution was preferred mainly for transfer (9/16); coordination was split; conflict detection, resolution and QoS mostly advisory. Adjust when trust is gained.

One timeout does not fit all

A fixed 30 s execution window was too short in dense traffic. Differentiate by action type and adapt to workload.

Close the loop with intent

Intent was recognised in real time but not yet used by the support logic, it’s the key capability to integrate next.

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