

# Empirical results from the MAHALO project: personalized and transparent AI for CD&R

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**MAHALO**

Modern ATM via Human/Automation  
Learning Optimisation



**li.u** LINKÖPING  
UNIVERSITY



 **TU Delft**

 **CHPR**

 **deepblue**

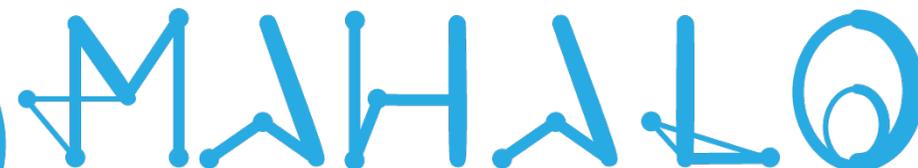
  
**EUROCONTROL**



**ANACNA** 



- Conducted a state-of-the-art review of ML advances to CD&R;
- Developed & demonstrated a ML CD&R capability;
- Designed an experimental user interface & simulation capability;
- Integrated ML capabilities with the simulator & interface;
- Conducted a pair of two-phase experiments (Training pre-test, and Main experiment) with 36 controllers that varied ML model conformance and advisory transparency
- Provided results showing:
  - effects of strategic conformance on advisory response;
  - advisory response was affected by the match between preferred and proposed separation distance; and
  - no effects of transparency.



**Modern ATM via Human/Automation  
Learning Optimisation**



@benwhitephotography



*Design challenge*

## Understanding automation

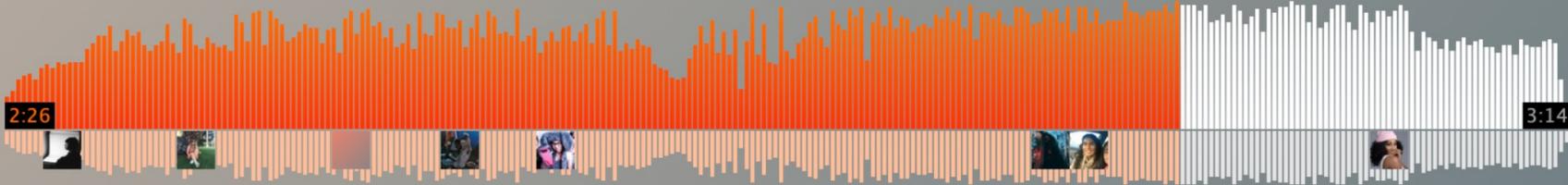
- Why does it propose that solution?



# SoundCloud Weekly Private

Made for Wes117

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- 1 Yngcult - **The Electric (feat. Madison Gold)** 👍 🔄 📁 🔗 ⋮
- 2 LOYAL - Light Up For You ▶ 104K
- 3 Wales - Lose My Mind ▶ 481K

All of SoundCloud. Just for you.

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Artists featured

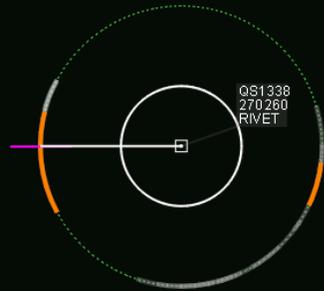
**Yngcult**  
 2,260 26 Follow



# MUFASA (2011 – 2015)



## Record solutions



## Capture strategies



## Replay solution



50% conformal



50% non-conformal

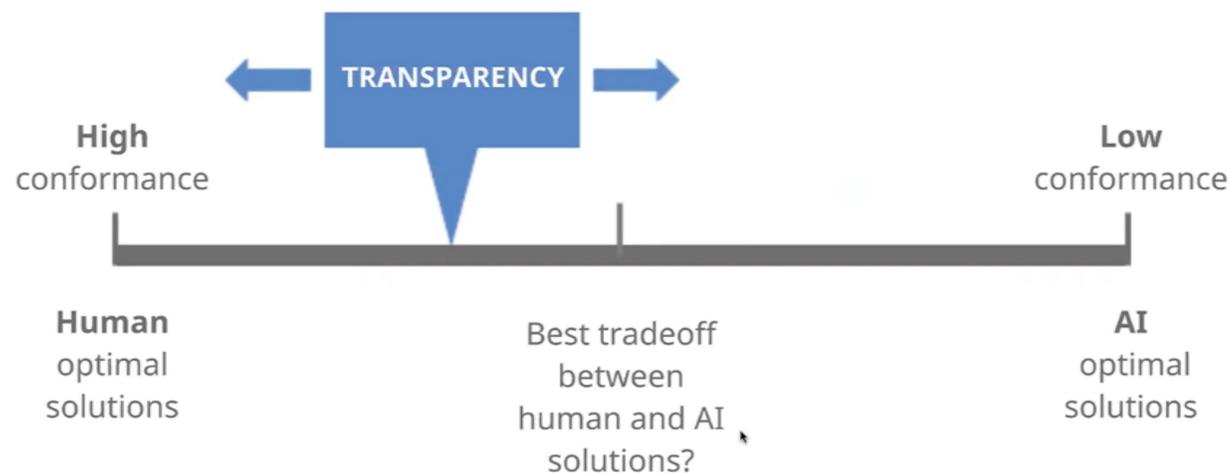
Conformal advisories had significantly higher acceptance, higher agreement, and faster response time than non-conformal advisories. ATCOs rejected their own advisories in 25% of all cases.

# MAHALO objectives

Develop ML solutions for CD&R via:

- **Supervised Learning** - to mimic controller solutions (conformal)
- **Reinforcement Learning** – to generate (ATCO independent) optimized solutions

Empirically evaluate conformance and transparency



**Goal:** Derive general design lessons

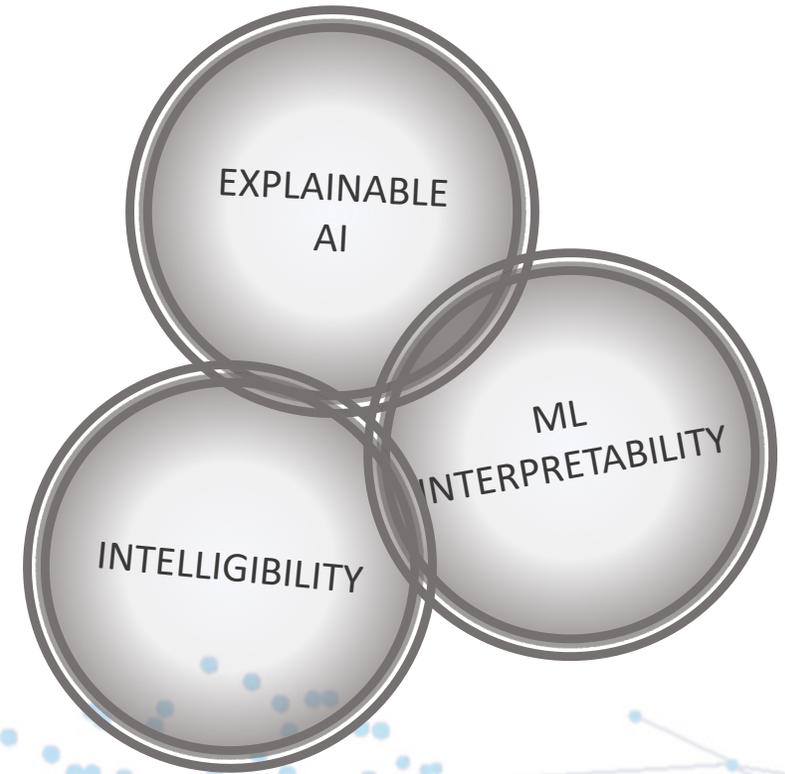
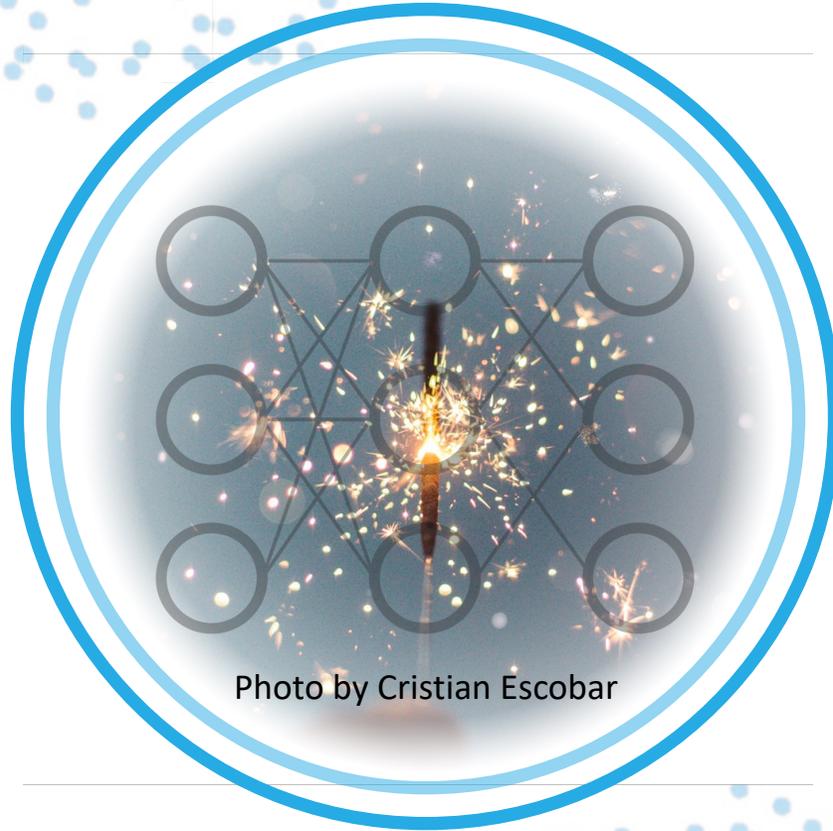
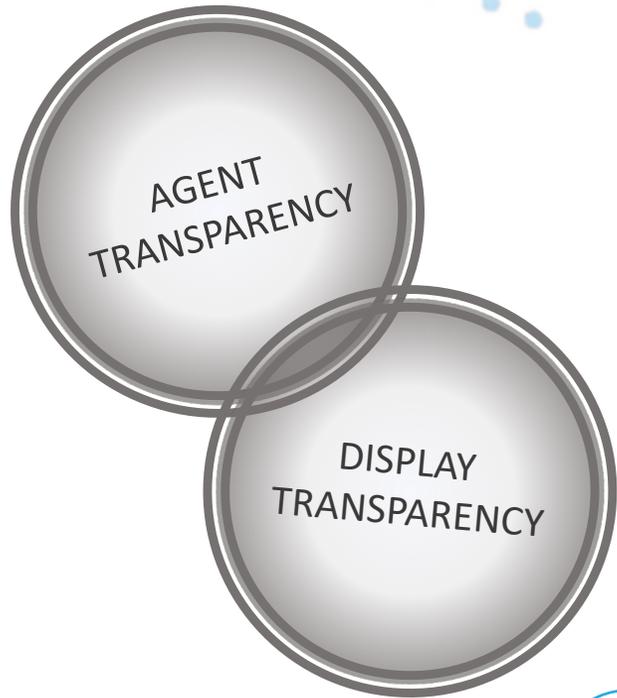


# Strategic conformance



*“the apparent strategy match between human and automation solutions”*

# Automation transparency



*“the automation’s ability to afford understanding and predictions about its recommendations and behavior”*

# How should we build Machine Learning?



## Conformance

Does automation seem to match human strategies?

## Transparency

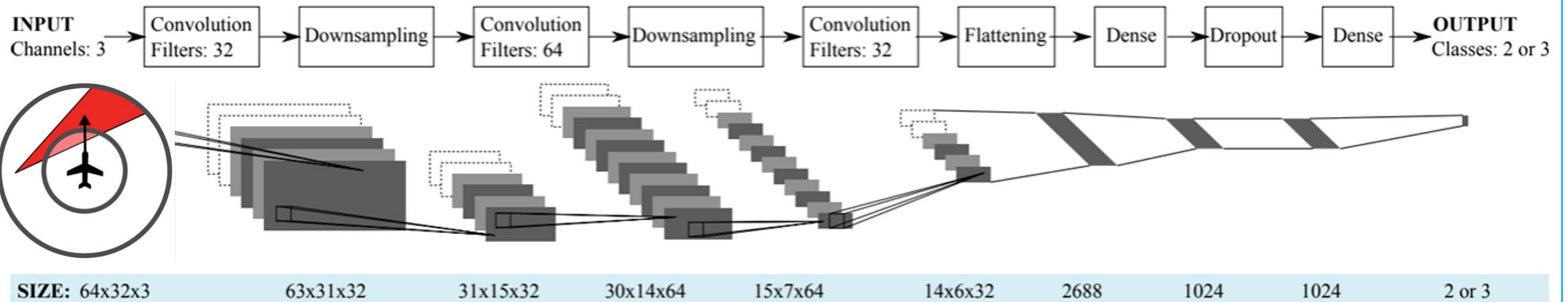
Is automation's inner process explainable to human?

		TRANSPARENCY	
		Low	High
CONFORMANCE	Low	<b>Stupid automation</b> <i>"It's doing a strange thing, and I don't understand why..."</i>	<b>Peculiar automation</b> <i>"It's doing a strange thing, but I understand why..."</i>
	High	<b>Confusing automation</b> <i>"It's doing the right thing, but I don't understand why..."</i>	<b>Perfect automation</b> <i>"It's doing the right thing, and I understand why..."</i>

# Supervised Learning (conformal advisories)

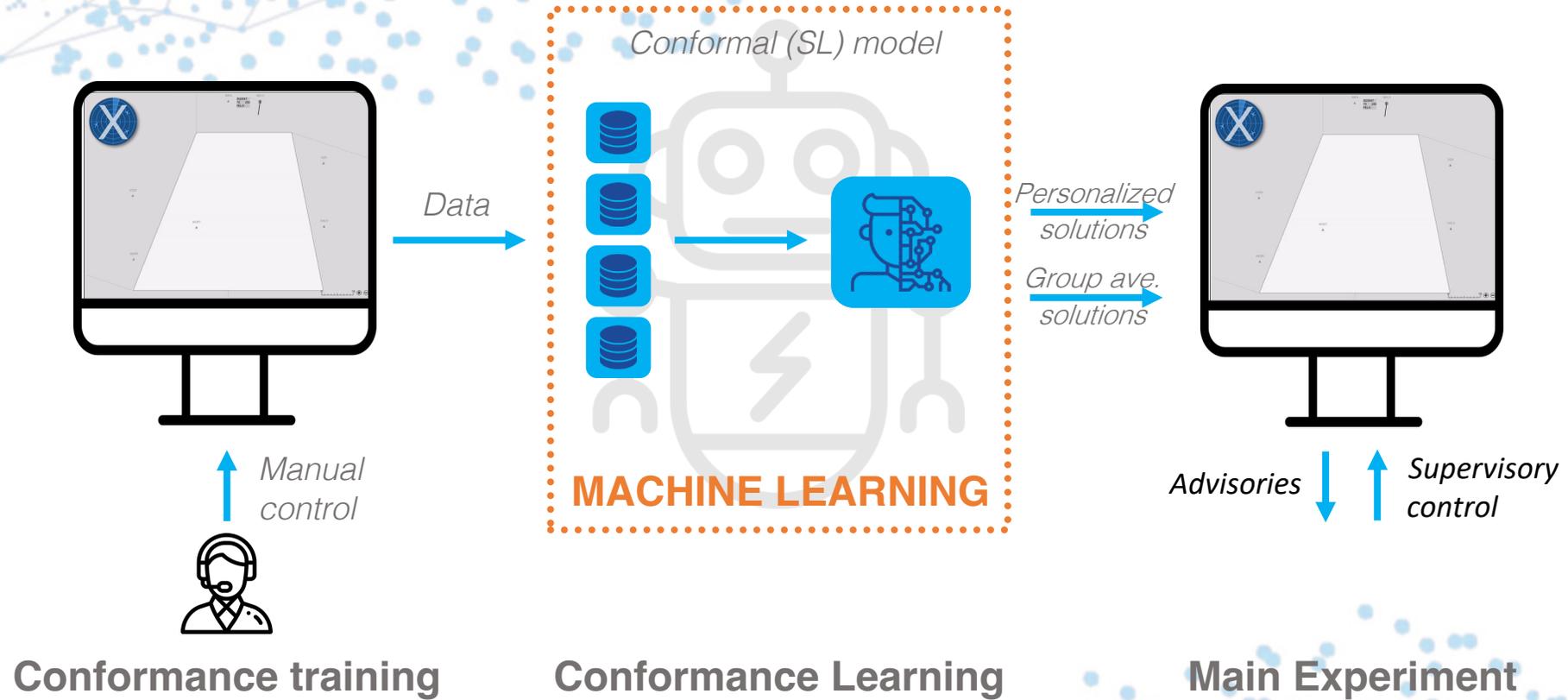


**Convolutional Neural Networks (CNN)** – good for processing image data



**Goal:** Build [personal](#) and [group](#) prediction model for conflict resolutions

# Experimental setup



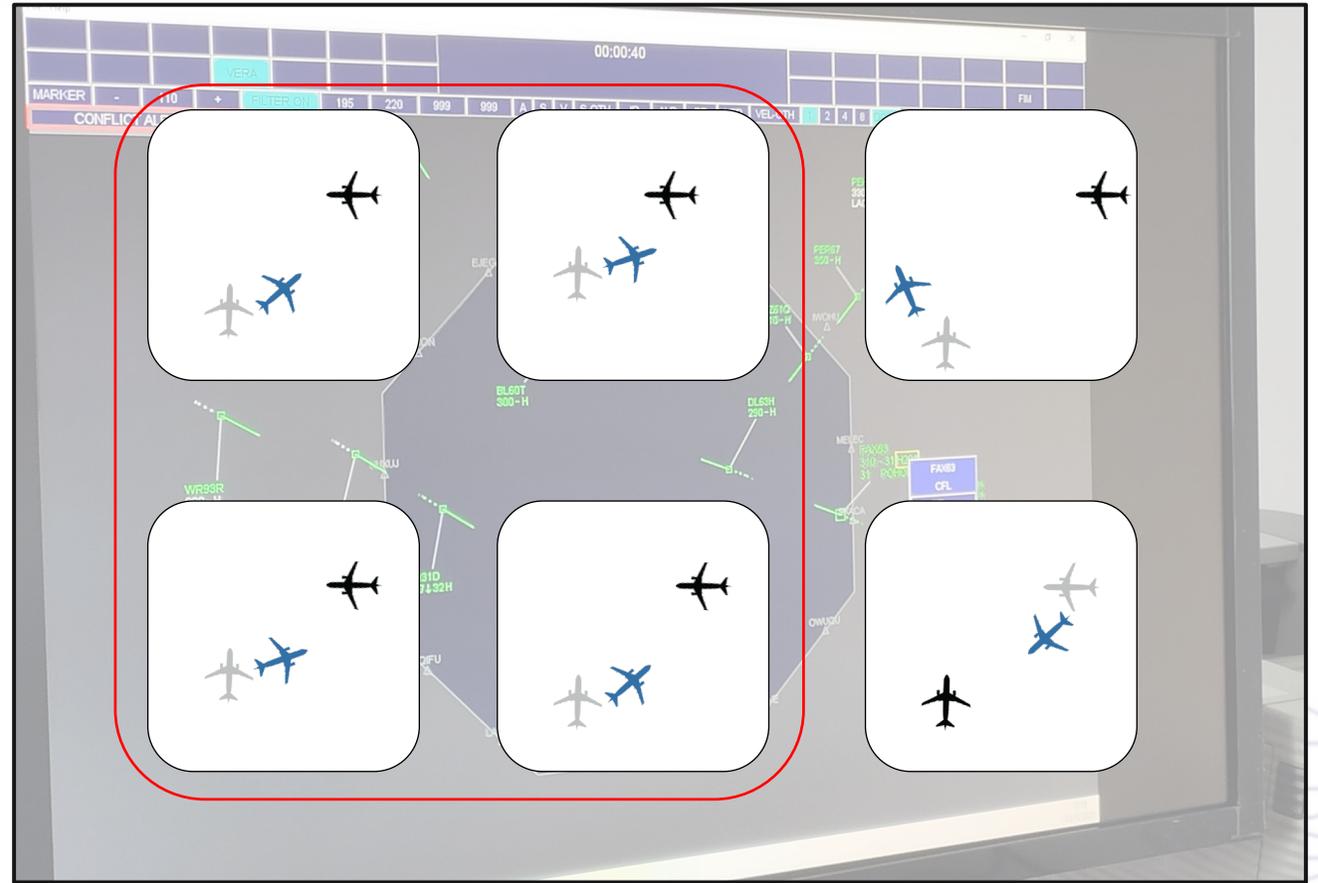
# Personal model creation



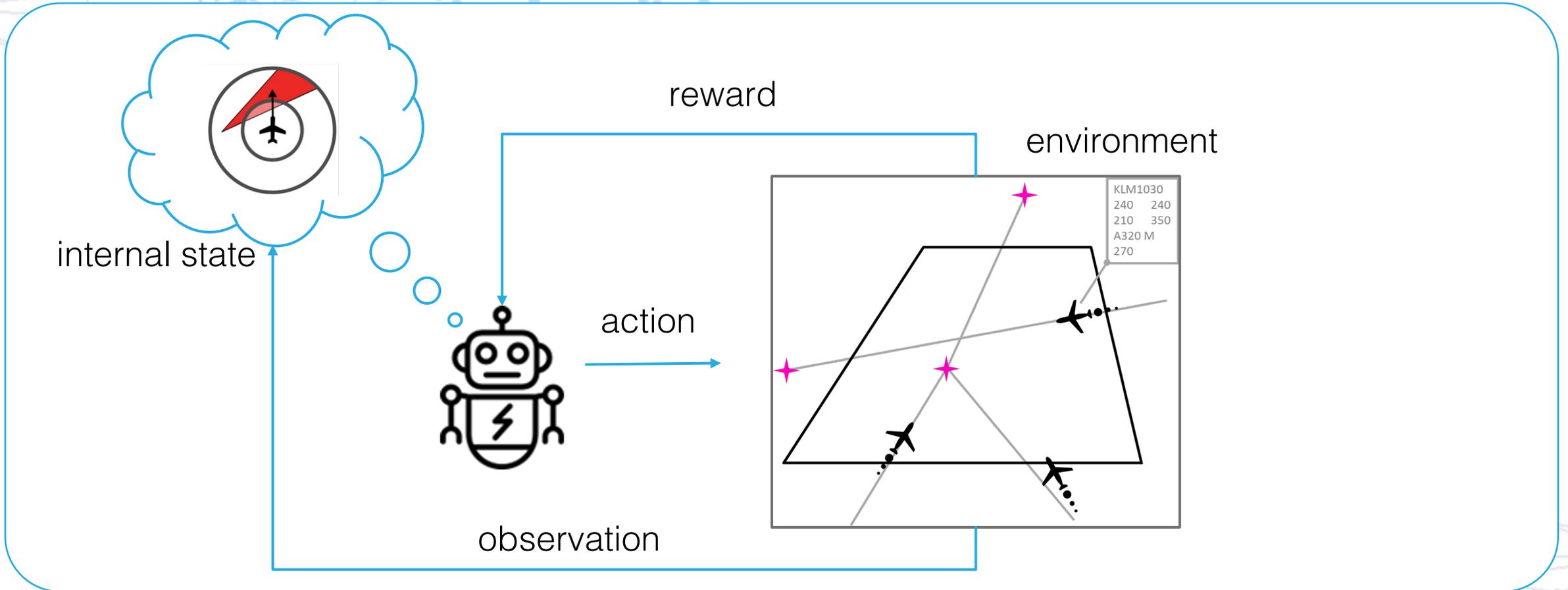
## Manual analysis of solutions

(6 solutions per scenario)

- Detection time
- Aircraft choice
- Resolution type
- Heading direction
- Separation margin



# Reinforcement Learning (optimized advisories)



**Goal:** Build **optimized** prediction model for conflict resolutions



# Experiment

## Participant task

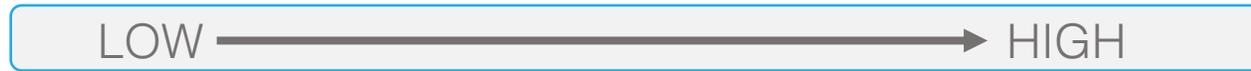
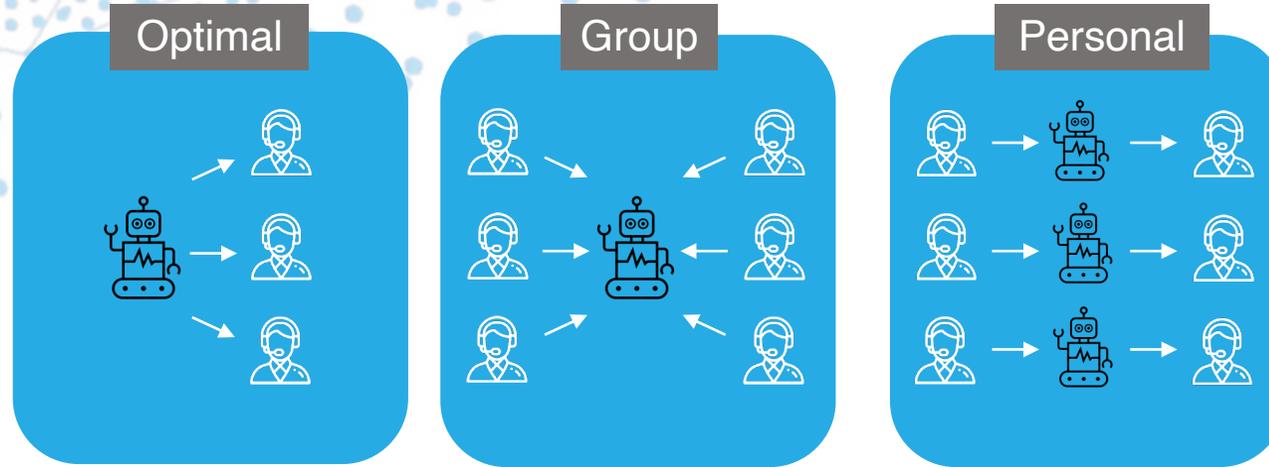
Supervise automation controlling all traffic and inspect/accept/reject resolution proposals issued by automation.



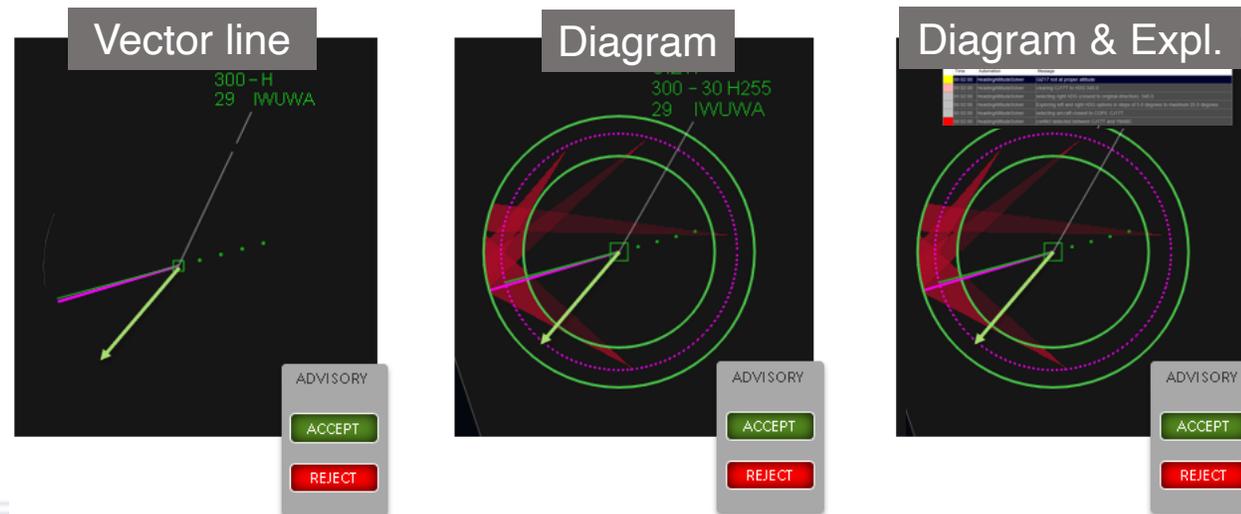
# Conformance & Transparency variables



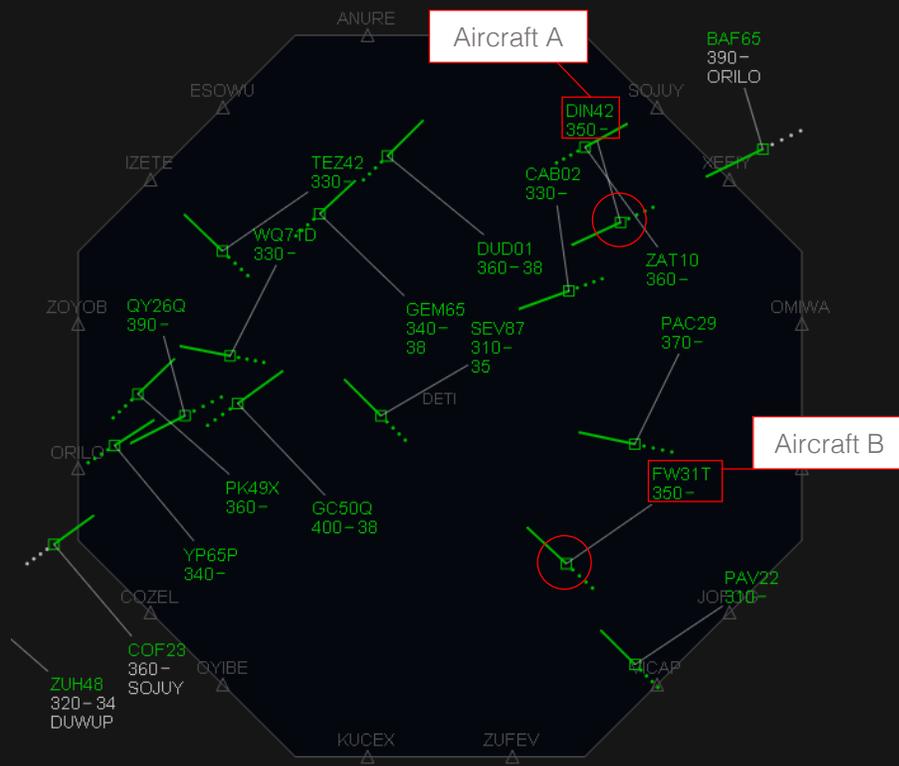
Conformance



Transparency



# Scenarios



Scenario A



Scenario B

# Advisory conformance

## group models, optimal models



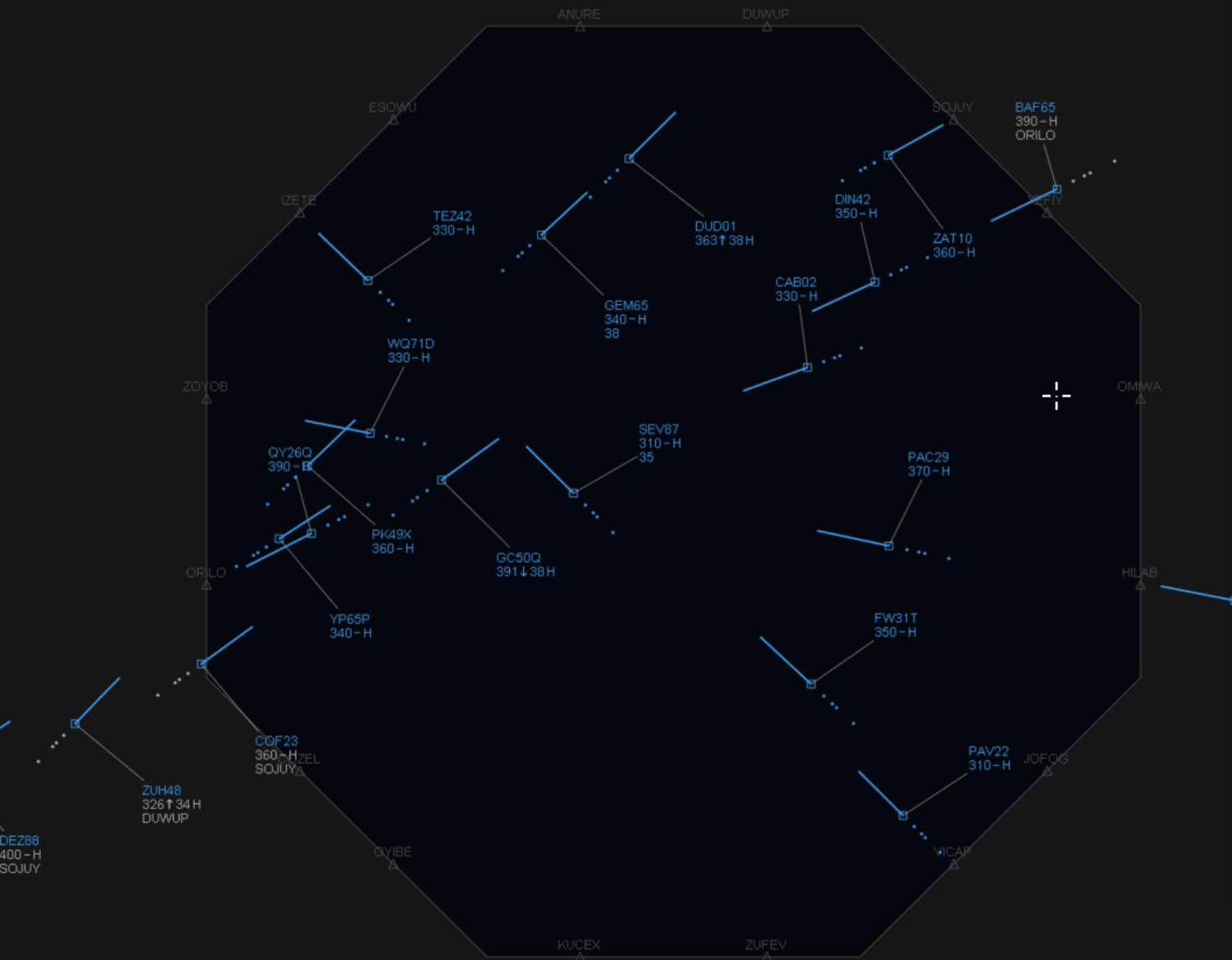
Advisory conformance	SIM1		SIM2	
	Scen. A	Scen. B	Scen. A	Scen. B
<b>GROUP</b>				
<i>Advisory time</i>	48	51	54	58
<i>Control action</i>	In front	In front	In front	In front
<i>Aircraft</i>	A	A	A	A
<i>Resolution direction</i>	Right	Right	Right	Right
<i>CPA (aim)</i>	10.5	9	6.9	6.6
<i>Heading deviation</i>	30	20	20	15
<b>OPTIMAL</b>				
<i>Advisory time</i>	20	20	114	96
<i>Control action</i>	Behind	Behind	Behind	In front
<i>Aircraft</i>	B	A	A	B
<i>Resolution direction</i>	Right	Left	Left	Left
<i>CPA (aim)</i>	6.6	7.7	10.7-10.8	10.3-10.6
<i>Heading deviation</i>	17	-15	-40	-29

MTCD VERA X

CONFLICT ALERT MESSAGE

Events

Time	Agent	Message



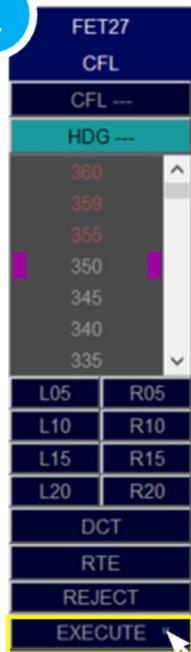
TURN FW31T behind DIN42 to aim at 8.0 nm separation

# Interacting with ML advisories



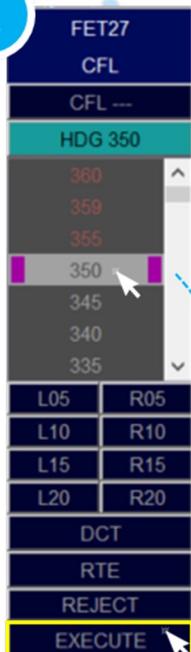
## ACCEPT

1



Press the EXECUTE button

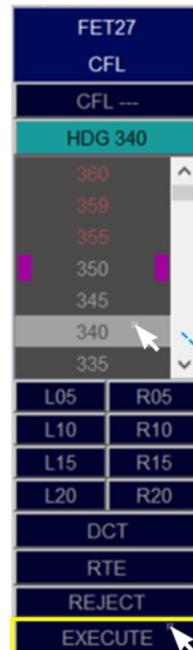
2



Click on the proposal, which makes the mouse cursor move automatically to EXECUTE and press EXECUTE

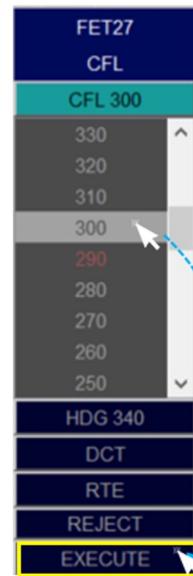
or

## NUDGE & ADJUST



Click another value and press EXECUTE

## CHANGE



Click another clearance type (here, altitude) and press EXECUTE.

## REJECT



Press the REJECT button, allowing interaction with the other aircraft involved in the conflict.

# Dependent measures



**The system solved the conflict the same way I would have.**

1 2 3 4 5 6

Disagree  
highly

Agree  
highly

**I can understand why the system suggested that solution.**

1 2 3 4 5 6

Disagree  
highly

Agree  
highly

## AFTER EACH SOLUTION

- Acceptance response
- Agreement rating
- Advisory conformance rating
- Advisory understanding rating
- Response time
- Delta closest point of approach (CPA) distance
- Workload rating

# Results



## Conformance effects

Measure	SIM1		SIM2	
	Scen. A	Scen. B	Scen. A	Scen. B
Agreement ratings	👍		👍	👍
Workload ratings		👍		
Delta CPA distances (nm)	👍		👍	👍
Response time (s)			👍	

## Conformance and transparency effects

Acceptance response	👍		👍	👍
Advisory conformance rating	👍		👍	👍
Advisory understanding rating			👍	👍

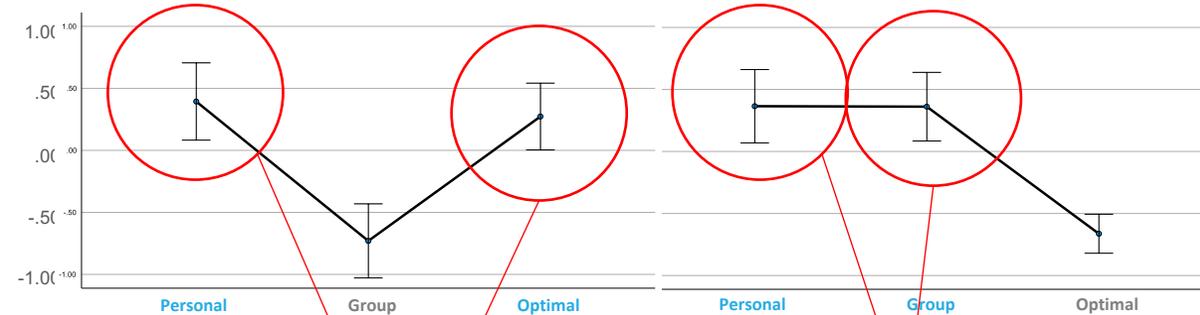
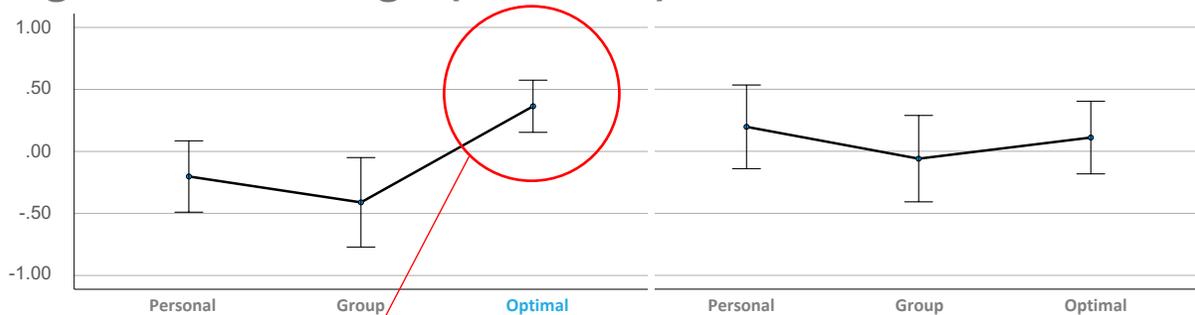
SIM1, Scen. A

SIM1, Scen. B

SIM2, Scen. A

SIM2, Scen. B

## Agreement ratings (z-scored)



## Acceptance response

Optimal preferred

--

Personal preferred

Personal and group preferred

## Conformance rating *(The system solved the conflict the same way I would have)*

Optimal preferred

--

Personal and optimal preferred

Personal and group preferred

## Understanding rating *(I understand why the system suggested that solution)*

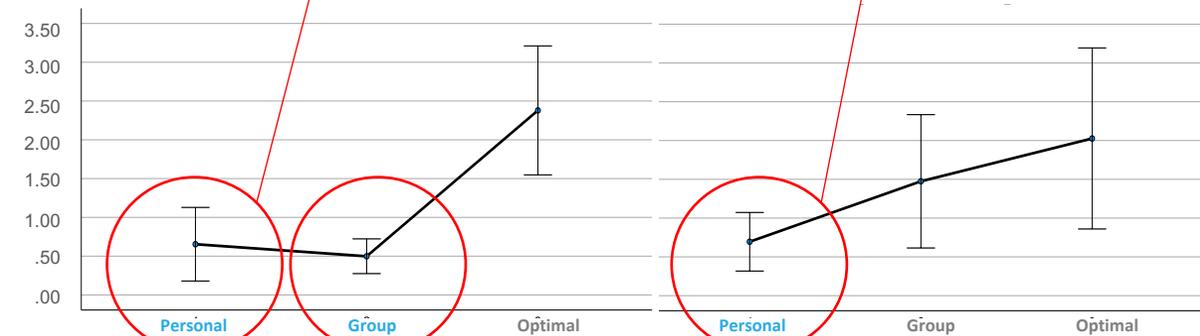
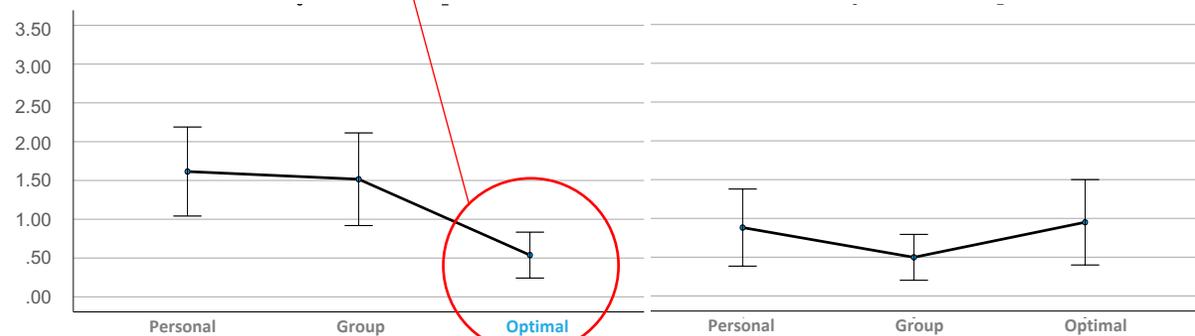
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Group less understandable

Optimal less understandable

## Delta CPA distances (nm)

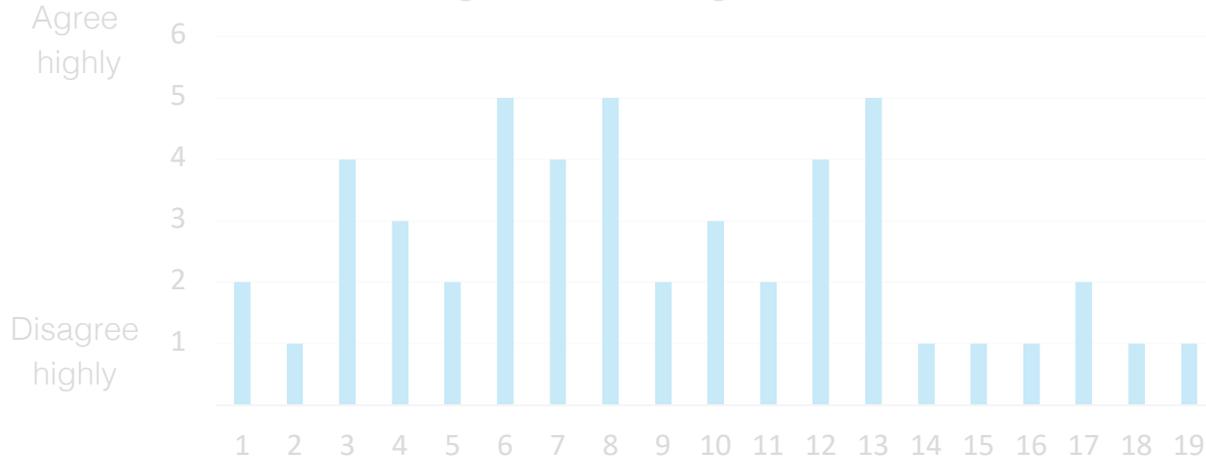


# Acceptance & agreement

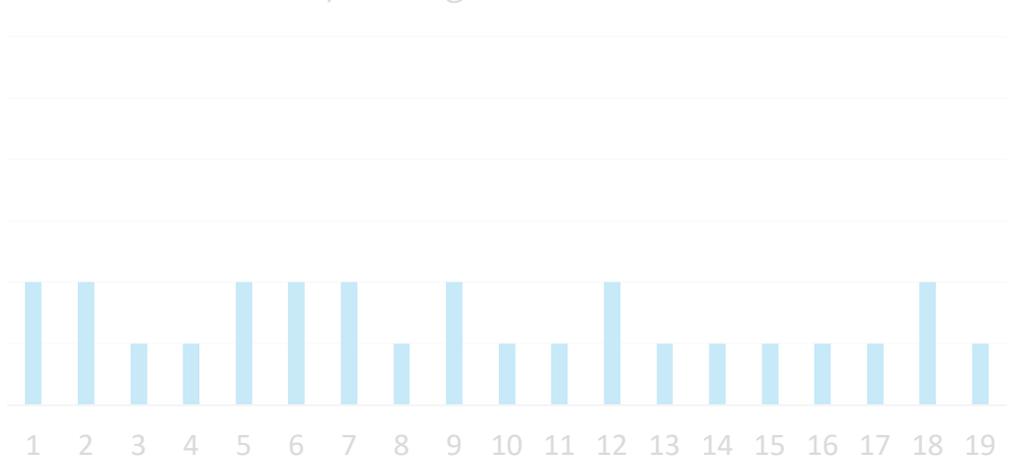


SIM1

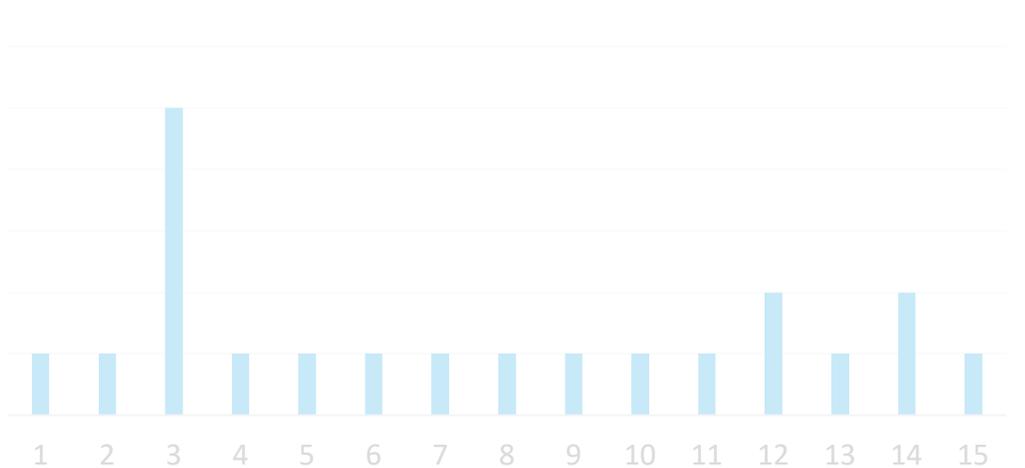
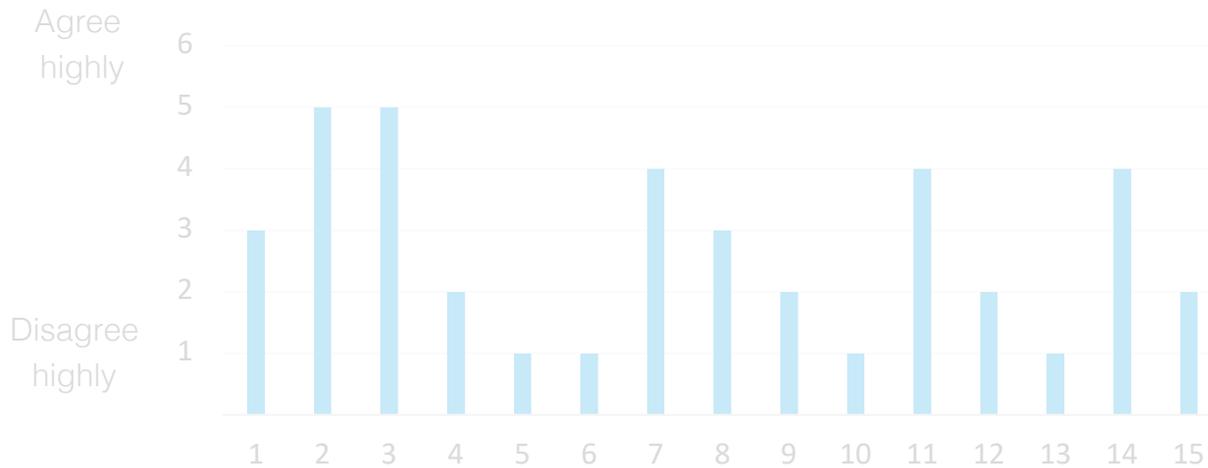
*"I accepted resolution advisories even though I did not agree with them"*



*"I accepted resolution advisories without inspecting the conflict"*



SIM2



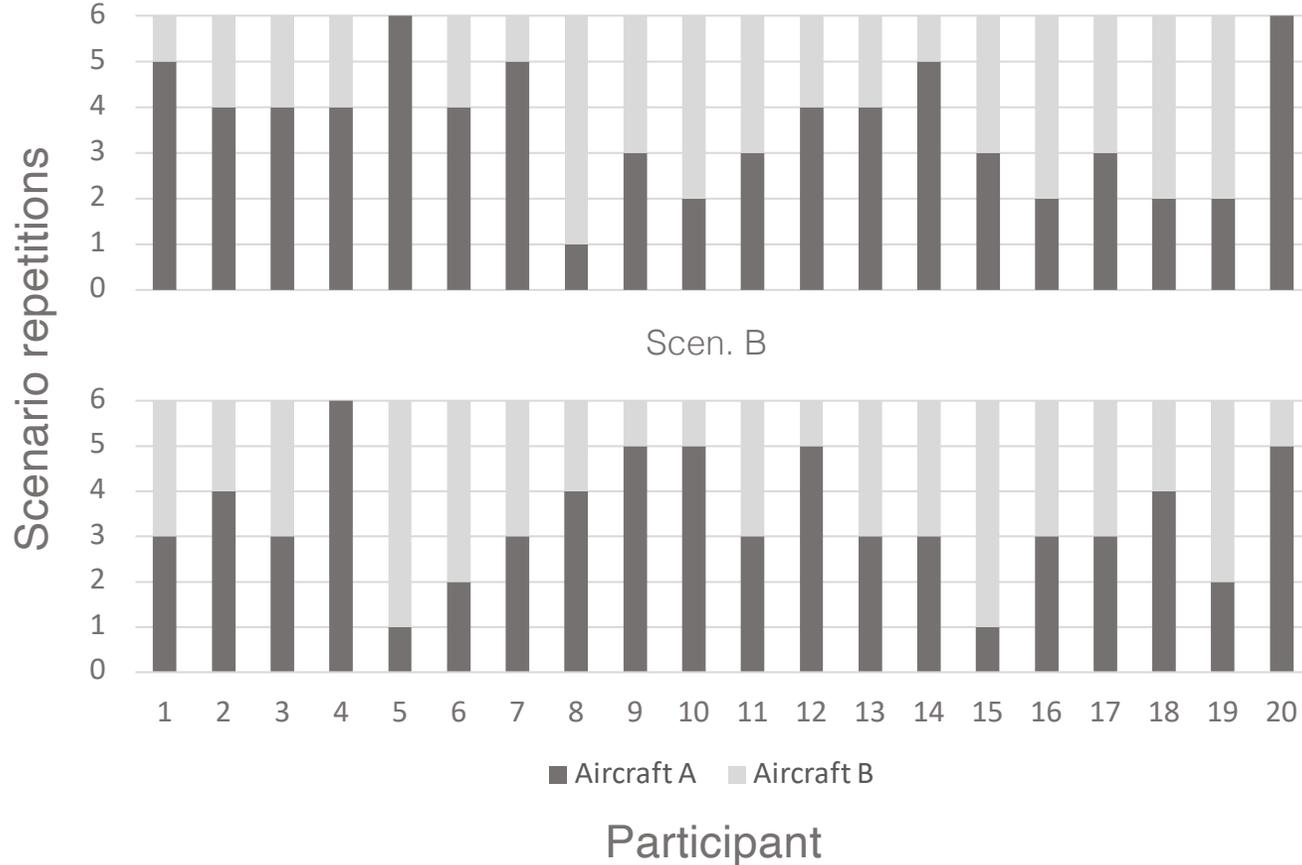
# Individual differences



## Aircraft choice

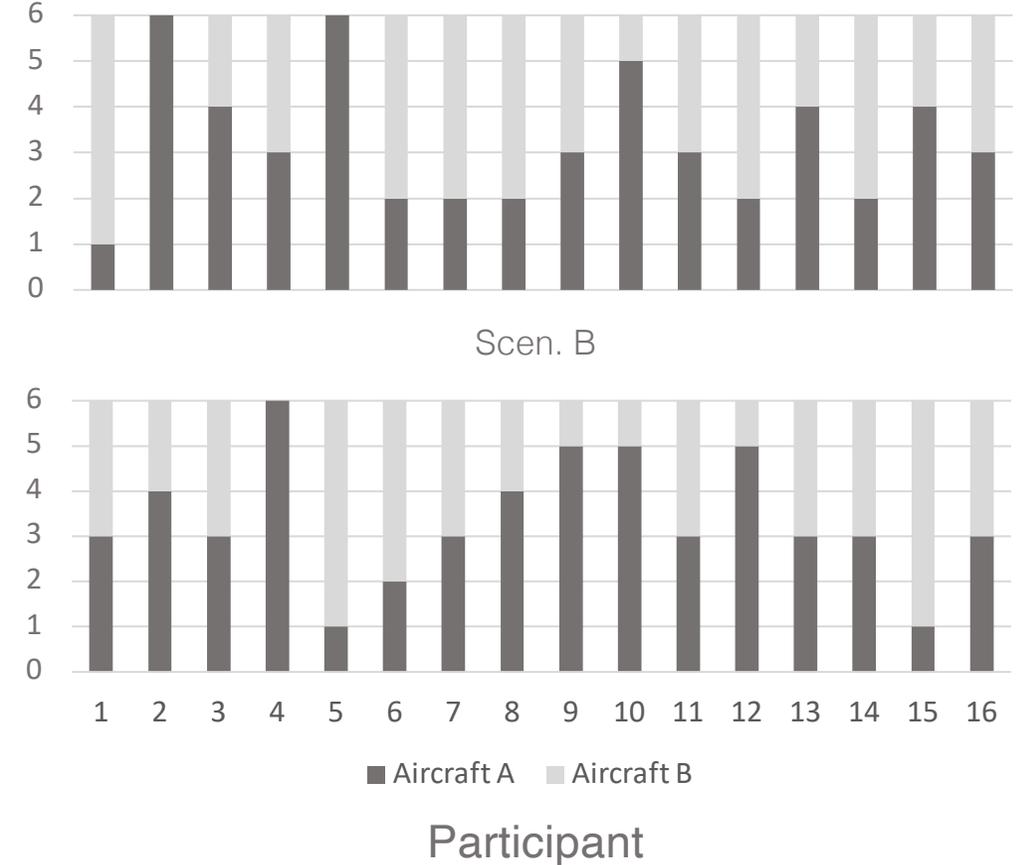
SIM1

Scen. A



SIM2

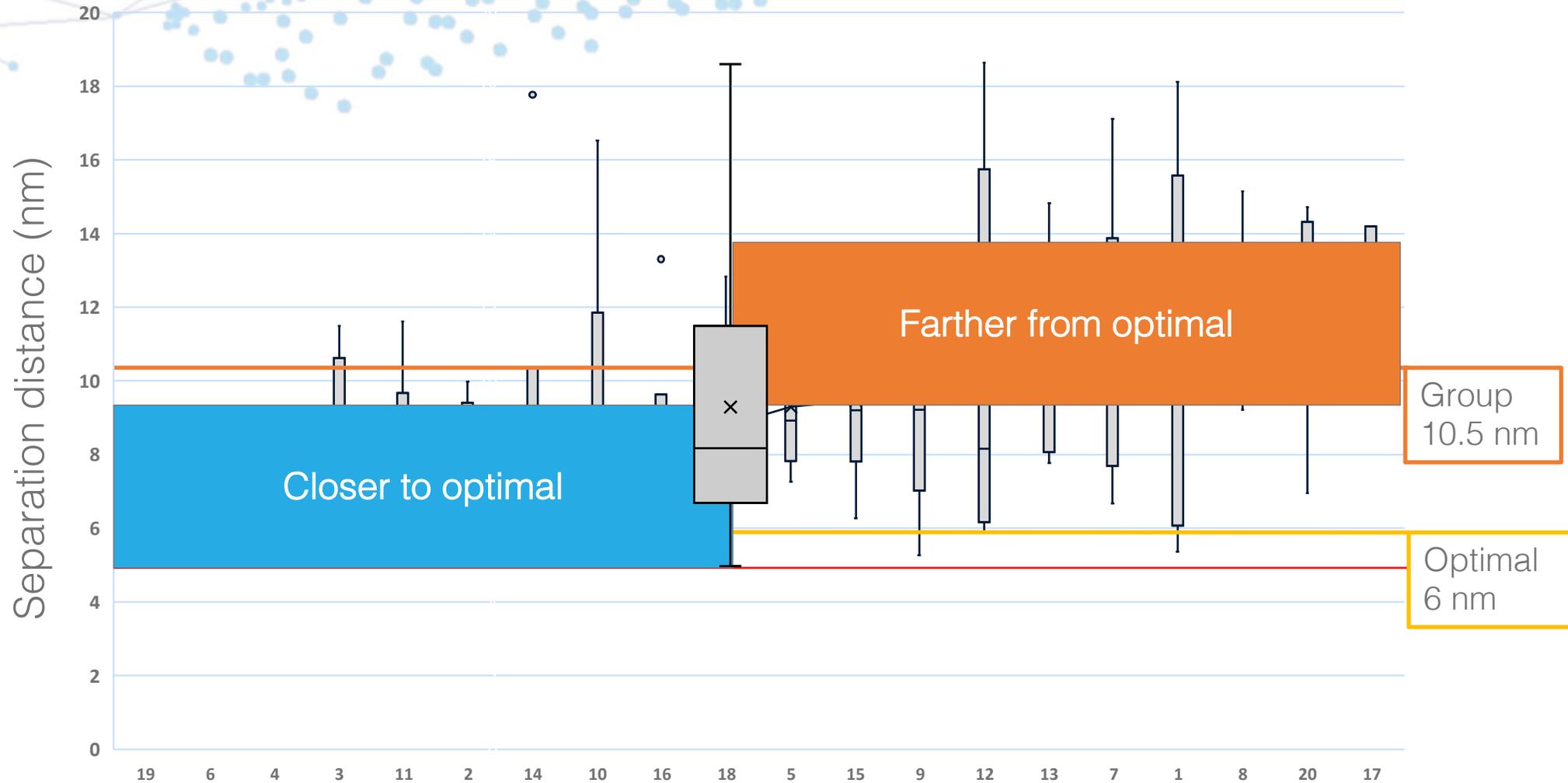
Scen. A



# Individual differences



Scen. A, SIM 1 (order of earliest interaction)

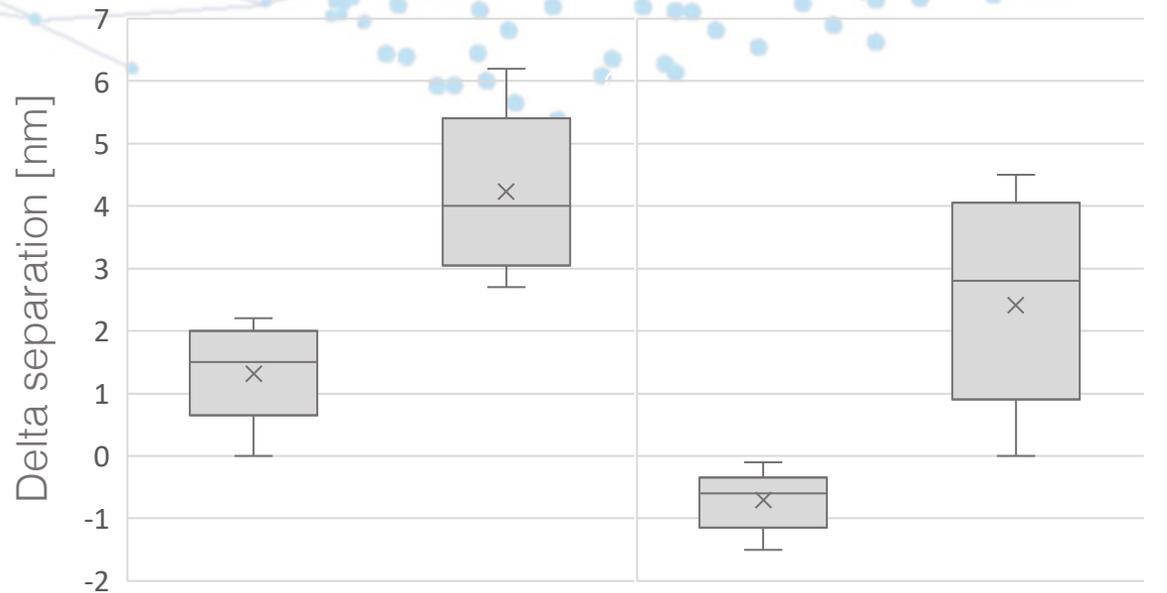


(n=20; S=108/120)

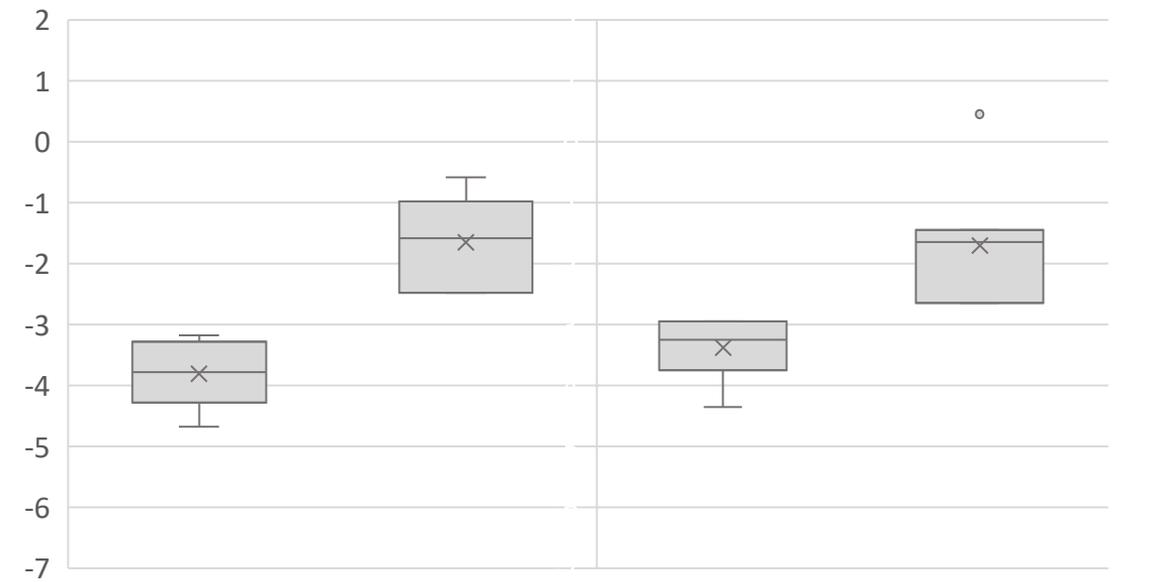
# Individual differences



SIM1



SIM2



## Delta Separation

*Difference in nautical miles (nm) between personal model separation distance and optimal model separation distance.*

# Results



*Differences between ATCO groups depending on how close their separation distance preferences are relation to the target CPA in the optimal advisory*

Measure	SIM1		SIM2	
	Scen. A	Scen. B	Scen. A	Scen. B
Agreement ratings	👍 T0	👍 T2		
Workload ratings			👍 T1	
Delta CPA distances (nm)		👍 T2		👍 T2
Response time (s)			👍 T0	
Acceptance response		👍 T2		
Advisory conformance rating		👍 T2		👍 T0
Advisory understanding rating	👍 T2			👍 T0

# Results



*Close to optimal*



*Far from optimal*



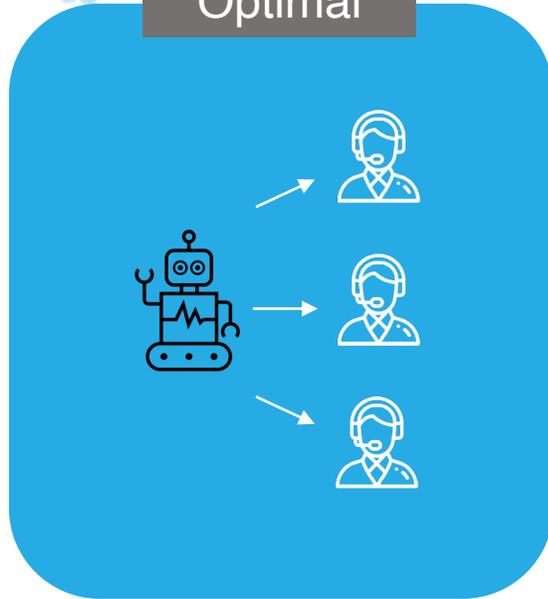
Group with a preferred separation distance **closer to optimal CPA:**

- Accepted advisories with less interference
- Higher agreement ratings
- Higher conformance ratings
- Higher understanding ratings
- Smaller CPA distances
- Lower workload ratings
- Faster response time

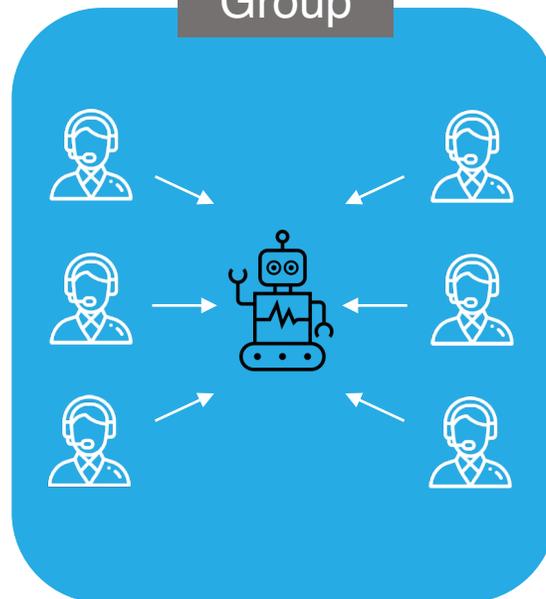
# Inconsistent conformance effects



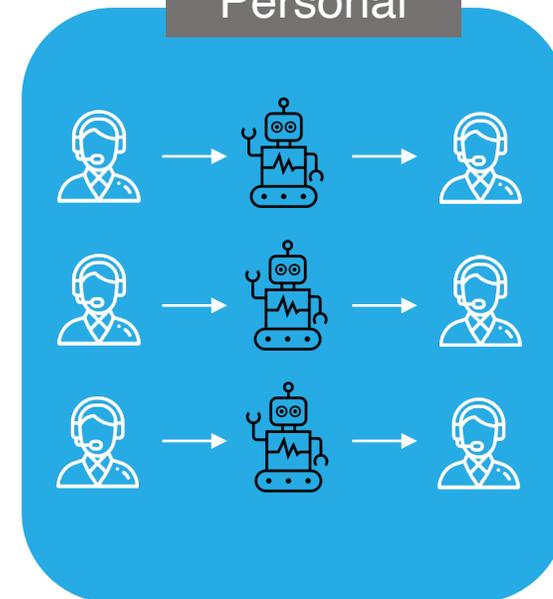
Optimal



Group



Personal



Preferred in SIM1,  
Scen. A

- Higher agreement
- Higher conformance ratings
- Lower delta CPA distances

Preferred in SIM2

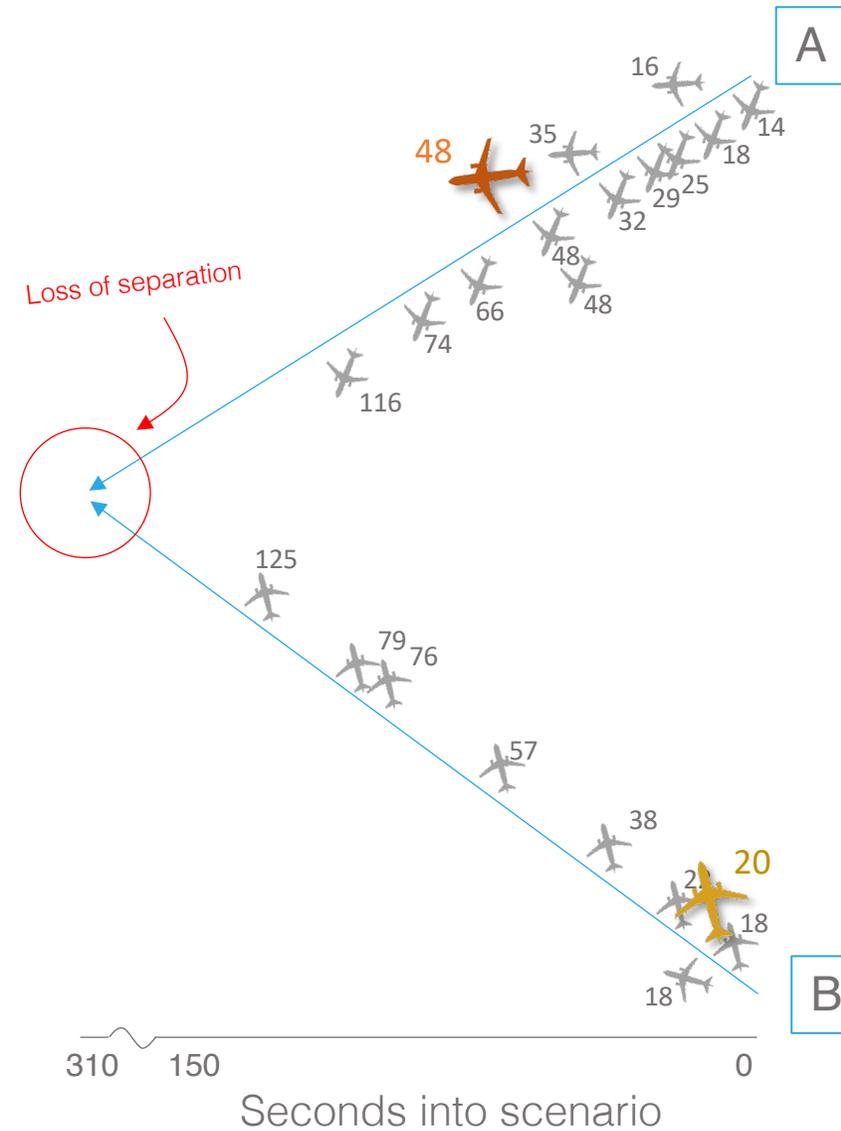
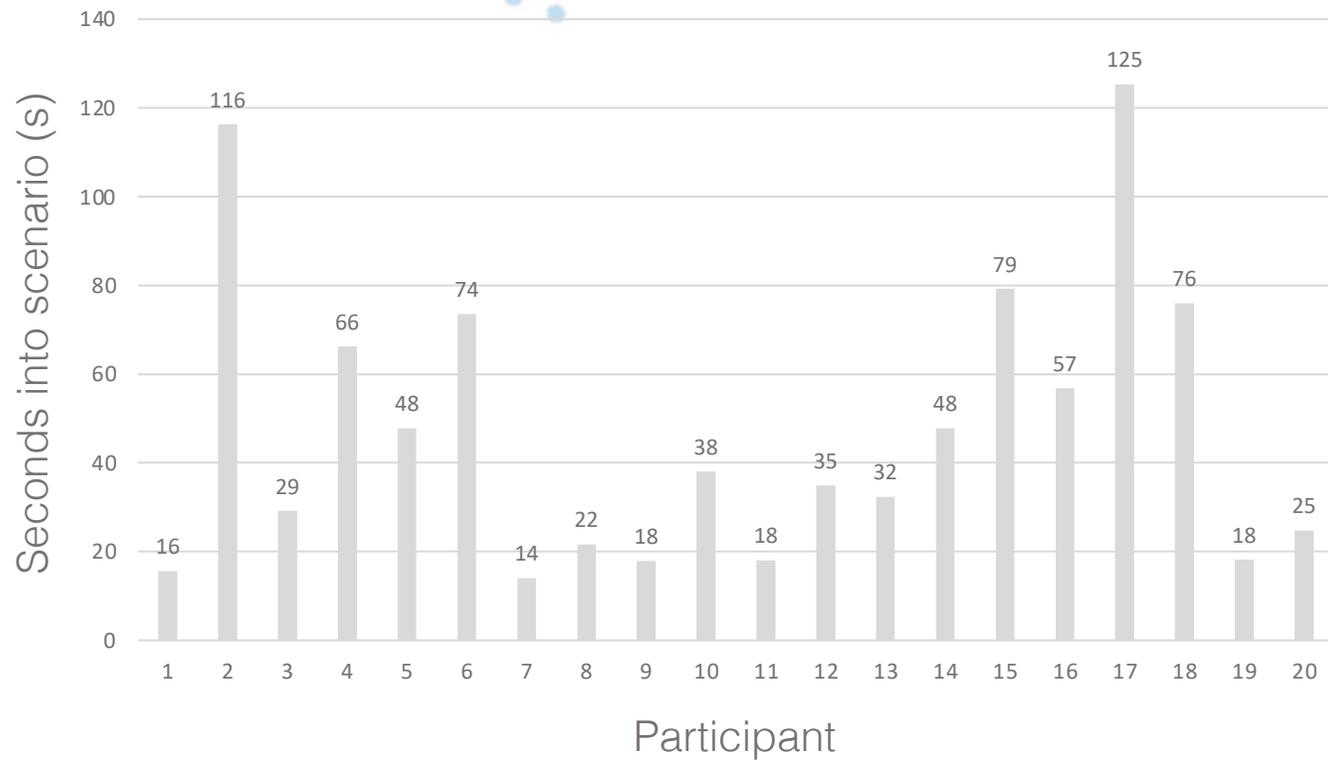
- Higher agreement
- Lower delta CPA distances

# Advisory conformance

Scen.A, SIM1



Advisory time



# Where are the transparency effects?



Vector line

GIZ17  
300-H  
29 IWUWA

ADVISORY

ACCEPT

REJECT

Diagram

GIZ17  
300-30 H255  
29 IWUWA

ADVISORY

ACCEPT

REJECT

Diagram & Expl.

Automation Messages

Time	Substation	Message
00:02:00	HeadingAltitudeControl	GIZ17 not at proper altitude
00:02:00	HeadingAltitudeControl	clearing C4171 to HDG 345.0
00:02:00	HeadingAltitudeControl	selecting right HDG (closest to original direction): 345.0
00:02:00	HeadingAltitudeControl	Exploring left and right HDG options in steps of 1.0 degrees to maximum 25.0 degrees
00:02:00	HeadingAltitudeControl	selecting arrival (closest to COP): C4171
00:02:00	HeadingAltitudeControl	conflict detected between C4171 and 1949C

GIZ17  
300-30 H255  
29 IWUWA

ADVISORY

ACCEPT

REJECT

LOW

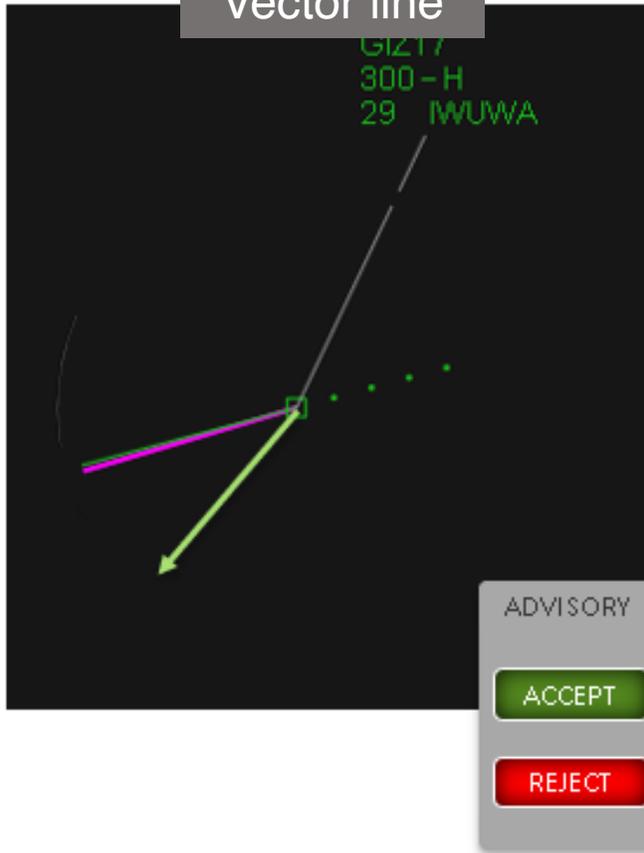


HIGH

# Transparency & separation distance

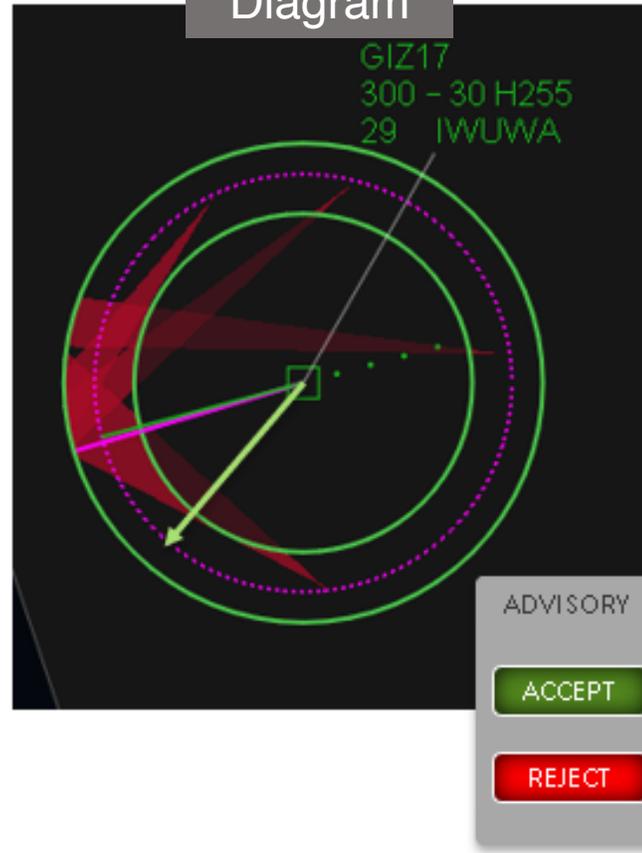


Vector line



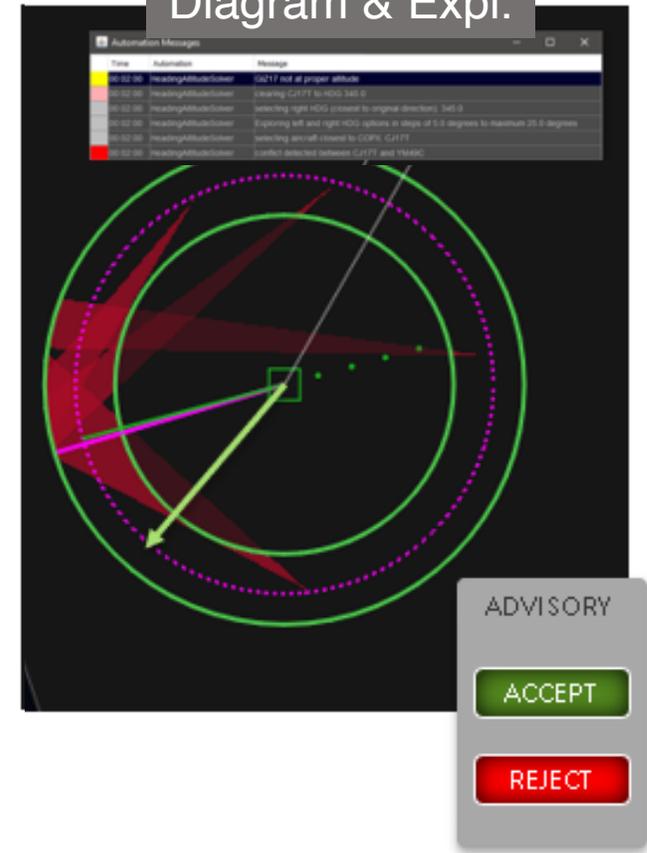
No information on separation distance

Diagram



Separation can be judged by comparing distance between vector with red triangle

Diagram & Expl.



Target separation part of explanation

# Guidelines for future AI systems in ATC

ML/AI Design

**Personalisation**

Transparency

HCI

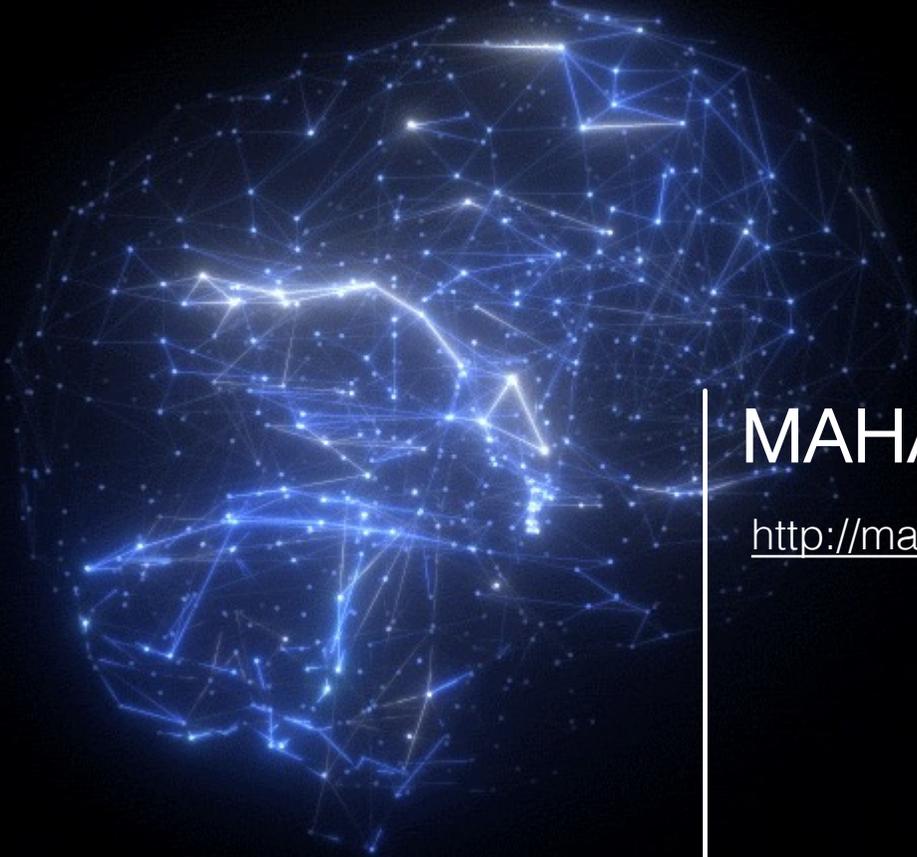
General

- Future ATC systems should acknowledge individual differences.
- Future ATC system should explore personalisation mechanisms to benefit human-AI teaming.
- Future systems should consider individual preferences in problem solving only when appropriate.
- If the system goes against the individual's preferences, the system should be able to provide an explanation for why the system believes its solution to be better than the individual's.

## Future research

- More research on strategic conformal automation
- Personalized or tuneable solution parameters (e.g., target separation distance)
- Personal vs optimal parameters
- What to make transparent/explainable





# MAHALO for listening

<http://mahaloproject.eu>

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