Delft University of Technology

Document Version
Final published version

Licence
Dutch Copyright Act (Article 25fa)

Citation (APA)
Lyu, W., Borst, C., Van Paassen, M. M. R., & Mulder, M. (2025). How Do Visualization Choices Affect Human Decision-Making? A Case Study in Air Traffic Control. In *2025 IEEE International Conference on Systems, Man, and Cybernetics: Navigating Frontiers: Smart Systems for a Dynamic World, SMC 2025 - Proceedings* (pp. 7109-7114). (Conference Proceedings - IEEE International Conference on Systems, Man and Cybernetics). IEEE.
https://doi.org/10.1109/SMC58881.2025.11343058

Important note
To cite this publication, please use the final published version (if applicable).
Please check the document version above.

Copyright
In case the licence states "Dutch Copyright Act (Article 25fa)", this publication was made available Green Open Access via the TU Delft Institutional Repository pursuant to Dutch Copyright Act (Article 25fa, the Taverne amendment). This provision does not affect copyright ownership.
Unless copyright is transferred by contract or statute, it remains with the copyright holder.

Sharing and reuse
Other than for strictly personal use, it is not permitted to download, forward or distribute the text or part of it, without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license such as Creative Commons.

Takedown policy
Please contact us and provide details if you believe this document breaches copyrights.
We will remove access to the work immediately and investigate your claim.

This work is downloaded from Delft University of Technology.

2025 IEEE International Conference on Systems, Man, and Cybernetics (SMC)
October 5-8, 2025. Vienna, Austria

How Do Visualization Choices Affect Human Decision-Making? A Case Study in Air Traffic Control

Wenying Lyu, Clark Borst, M. M. (René) van Paassen and Max Mulder

2025 IEEE International Conference on Systems, Man, and Cybernetics (SMC) | 979-8-3315-3358-8/25/$31.00 ©2025 IEEE | DOI: 10.1109/SMC58881.2025.11343058

***Abstract*— Air traffic control is advancing digitalization by developing advanced decision-support systems, where the way information is presented to operators plays a central role in shaping performance. However, the effects of different visual representations within these systems on human decision-making remain not fully understood. In this study, we compared two Conflict Detection and Resolution (CD&R) tools: the Highly Interactive Problem Solver (HIPS) and the Solution Space Diagram (SSD). Although both systems are grounded in the same control problem, they differ in how they represent the control constraints that define conflict conditions and feasible responses. Through a human-in-the-loop experiment under low- and high-traffic conditions, we analyzed how these differences influence decision-making. Results showed that, particularly in low-density traffic, HIPS enabled quicker responses, fewer commands, and smaller safety margins, whereas SSD, despite receiving more favorable subjective ratings, led to greater variability in actions. These findings suggest that visualization significantly impacts decision-making consistency and efficiency. However, in highly complex environments, overall effectiveness may depend more on operators' ability to shift and adapt decision-making patterns facilitated by the interface than on specific visual elements.**

I. INTRODUCTION

In response to anticipated traffic increases, ensuring safety, efficiency, and stable growth has become a paramount concern for the air traffic management community in recent decades [1]. Addressing these challenges, the Single European Sky ATM Research (SESAR) program proposes a digitalization plan to advance automation in all phases of air traffic services [2]. While automation is set to revolutionize Air Traffic Control (ATC), it is crucial that human operators remain central as ultimate decision-makers and responsible agents [3]. However, integrating higher levels of automation into the ATC domain has consistently proven challenging, with the primary obstacle being low user acceptance rather than technical limitations [4]. Until now, Air Traffic Controllers (ATCOs) have carried out their regular control activities largely unassisted, with limited automated support accessible through the Plan View Display (PVD).

As a shift in the workplace paradigm seems inevitable, the most important task is to efficiently promote interaction between humans and (partially) automated systems. A key advancement in this area is the move towards human-centered automation, which acknowledges that the success of automated systems hinges not only on technological sophistication but also on fostering human adaptability and flexibility [5]. This shift is also reflected in the growing emphasis on Human-Machine Interface (HMI) design, where the displayed information must be carefully considered to minimize potential mismatches, while avoiding the widely-recognized drawbacks of automation [6].

All authors are with Control and Simulation section, Faculty of Aerospace Engineering, Delft University of Technology, Kluyverweg 1, 2629 HS Delft, The Netherlands W.Lyu-1@tudelft.nl

Over the past decades, various solutions have been proposed to address the demanding tasks of Conflict Detection and Resolution (CD&R) in ATC [7]. The proposed systems, coupled with their advanced HMI solutions, aim to generate and present complex spatial-temporal relationships between aircraft in a manner that is easily comprehensible to operators. The range of solutions varies significantly, from those still in the design and evaluation stages to others that have been set aside, with only a select few advancing to successful implementation in operational settings [8]. While the diverse approaches to tackling CD&R offer valuable insights, there is still a gap in understanding their comparable implications for human operators.

Interfaces developed within the same problem domain often differ in subtle yet impactful ways. For example, the Highly Interactive Problem Solver (HIPS) and the Solution Space Diagram (SSD) both translate the temporal and spatial relationships between aircraft into visual representations of the control space shaped by conflict constraints. Despite this conceptual similarity, their designs have evolved along distinct trajectories. HIPS, derived from earlier automation projects, displays conflict zones within the sector alongside the visualization of absolute tracklines. In contrast, SSD, originally based on Ecological Interface Design (EID), provides a centralized representation of conflict zones around the aircraft's velocity vector. Both systems continue to shape the development of decision-support tools in air traffic control [9]–[11]. The latest adaptation of SSD, the Lateral Obstacle and Resolution Display (LORD) within the ATC Real Ground-breaking Operational System (ARGOS), is set for deployment in real-world operations [12].

This paper presents a comparative study of two prominent CD&R interfaces, HIPS and SSD. While both tools have been evaluated in prior studies and validated in different experimental contexts, existing work has rarely examined them side-by-side from both theoretical and empirical perspectives. Grounded in the same operational challenge, we first examine how each interface structures and expresses key control elements through distinct visual strategies. We then empirically investigate how these visual differences affect operator behavior under controlled and varying traffic conditions. The results indicate that subtle design differences give rise to both converging behavioral patterns and divergent

Authorized licensed use limited to: TU Delft Library. Downloaded on May 06,2026 at 08:28:40 UTC from IEEE Xplore. Restrictions apply.

strategies, suggesting that visual encoding choices influence not only task performance but also how operators adapt their strategies to changing traffic conditions. In doing so, this study extends beyond prior system-level evaluations and provides practical insights for the design of future adaptive HMI systems in complex operational environments.

II. BACKGROUND

When the distance between two aircraft falls below the minimum separation – 1,000 feet vertically and 5 nautical miles horizontally – it results in a Loss of Separation (LoS) event. ATCOs are responsible for determining whether a LoS occurs and, if so, deciding on the appropriate resolution.

A. Problem Domain: CPA concept

Guided by the Closest Point of Approach (CPA) concept, the relationship between two aircraft with closest proximity can be evaluated. For a given pair of aircraft A and B, the controlled aircraft A has position $\mathbf{P_A}(t_0)$ and velocity vector $\mathbf{V_A}$, whereas observed aircraft B has position $\mathbf{P_B}(t_0)$ and velocity vector $\mathbf{V_B}$. The relative velocity vector of A with respect to B is denoted as $\mathbf{V_{rel}}$. As Fig. 1 shows, a conflict zone with the apex in $\mathbf{P_A}(t_0)$ is defined, bounded by λ_r and λ_f extending toward aircraft B's position with the radius of R_{pz}. If $\mathbf{V_{rel}}$ lies inside the conflict zone, spatial separation between the two aircraft will eventually be lost.

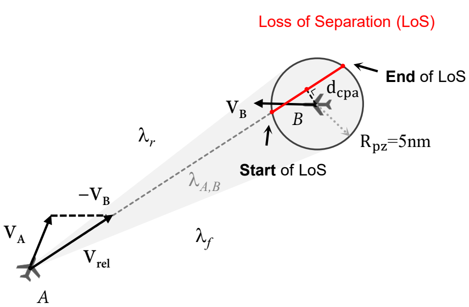


Fig. 1: CPA concept.

Based on these parameters, the time to reach the CPA equals to:

$$t_{cpa} = \frac{-(\mathbf{P_B}(t_0) - \mathbf{P_A}(t_0)) \cdot \mathbf{V_{rel}}}{\|\mathbf{V_{rel}}\|^2} \tag{1}$$

When $\|\mathbf{V_{rel}}\|$ is nonzero, the distance at CPA equals to:

$$d_{cpa} = \|\mathbf{P_B}(t_{cpa}) - \mathbf{P_A}(t_{cpa})\| \tag{2}$$

Time to LoS t_{los} can be calculated by solving:

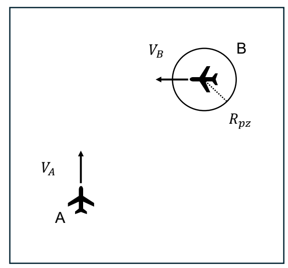
$$(\mathbf{V_{rel}} \cdot \mathbf{V_{rel}})t^2 + 2(\mathbf{P_{rel}} \cdot \mathbf{V_{rel}})t + \mathbf{P_{rel}} \cdot \mathbf{P_{rel}} = {R_{pz}}^2 \tag{3}$$

where $\mathbf{P_{rel}}$ represents the relative distance vector at time t_0, which equals to $\mathbf{P_A}(t_0) - \mathbf{P_B}(t_0)$. The solutions for (3) indicate the start and end of LoS. If $\|\mathbf{V_{rel}}\| = 0$, then the two aircraft are travelling in the same direction at the same speed, ensuring they remain parallel and at a constant distance from each other. If the distance between the two aircraft is less than R_{pz}, a LoS occurs as a special case. Otherwise, they will never encounter a LoS, and $t_{los} = \infty$. With each radar update, (1) to (3) must be reassessed to incorporate the updated positions and velocity vectors (both direction and magnitude) of the involved aircraft.

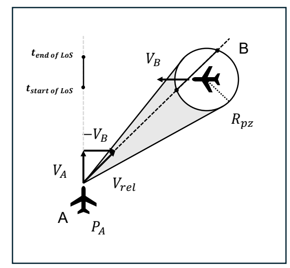
B. Decision-support tools

Within the same problem domain, both HIPS and SSD are designed to visually present conflict-related information on the PVD. The following subsections describe the development of these tools and highlight how they share similar principles despite their different visual representations.

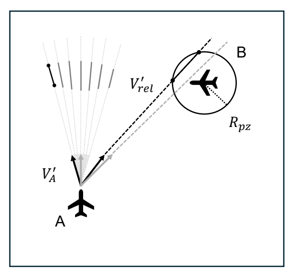
1) Highly Interactive Problem Solver (HIPS): HIPS, a tool developed within the PHARE Advanced Tools (PATs) program [13], provides colored zones and extended absolute tracklines for controlled aircraft, see its construction in Fig. 2. If the absolute trackline intersects the colored zones, it signals a potential conflict, which can be prevented by redirecting the trackline outside these zones.



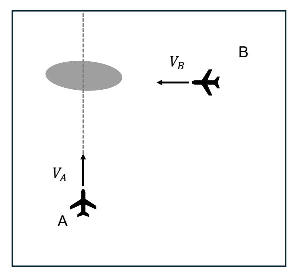
(a) Traffic geometry



(b) LoS durations and projections



(c) Iterative heading checks



(d) Coverage area and trackline

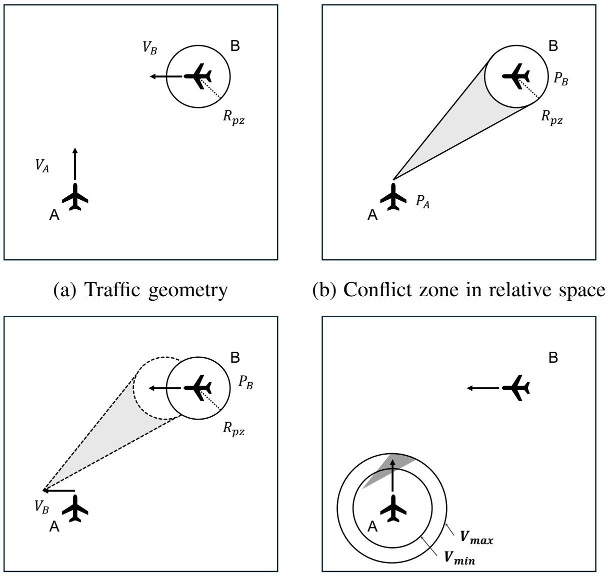
Fig. 2: Overview of HIPS construction.

2) Solution Space Diagram (SSD): Previous studies have demonstrated that the SSD is an effective tool for improving control performance in the CD&R task, with the underlying rationale detailed in [14]. As the construction shown in Fig. 3, SSD also uses colored regions to indicate potential conflict cases, and conflicts can be resolved by directing the velocity vector's tip outside these zones.

C. Visual variations

Despite differences in variable computation and visualization related to the CPA concept, HIPS and SSD share key similarities. Both tools convert relative motion data into absolute terms—HIPS through trajectory projections and SSD via vector addition—allowing users to visualize how the state vector interacts with displayed constraints. Specifically,

Authorized licensed use limited to: TU Delft Library. Downloaded on May 06,2026 at 08:28:40 UTC from IEEE Xplore. Restrictions apply.



(a) Traffic geometry (b) Conflict zone in relative space

(c) Vector addition (d) Speed constraints intersection

Fig. 3: Overview of SSD construction.

HIPS detects conflicts when its extended trackline intersects a conflict zone, while SSD detects conflicts when the tip of its velocity vector enters a conflict zone. Neither tool provides a direct resolution, but both enable users to formulate decisions based on the mentioned visual cues. In both systems, the urgency and severity of a conflict typically serve as key factors in determining intervention timing, as indicated by either the distance between the constraints and the ownship or the width of the constraints.

At the same time, there are certain differences between the two displays that might influence human perception and action preferences. For instance, SSD incorporates the speed envelope to support the perception of aircraft maneuverability, while HIPS focuses more on alternative headings. The layout styles of the displays also differ: SSD typically has overlapping triangles, draws attention to the selected aircraft, while HIPS displays more dispersed conflict zones across the screen, potentially encouraging broader traffic awareness. Additionally, SSD represents safe states across a range of speeds and headings, while HIPS requires frequent updates to accommodate even minor speed changes, as it depends on speed-constant preconditions.

III. EXPERIMENT DESIGN

A human-in-the-loop experiment was conducted to investigate effects of the SSD and HIPS representations of the CD&R problem on human decision-making behavior.

A. Apparatus

The ATC simulation software used in this study was a Java-based application called ‘SectorX’, designed to closely replicate a realistic controller working position at the Maastricht Upper Area Control Centre (MUAC). An example of the HIPS configuration within SectorX can be seen in Fig. 4. The simulations were run on a desktop computer equipped with a 30-inch HD display with a resolution of 2,560x1,600 pixels and a refresh rate of 60 Hz. Aircraft were simulated using the BADA aircraft performance. Instead of using radio telephony, participants controlled the aircraft using a standard computer mouse and keyboard.

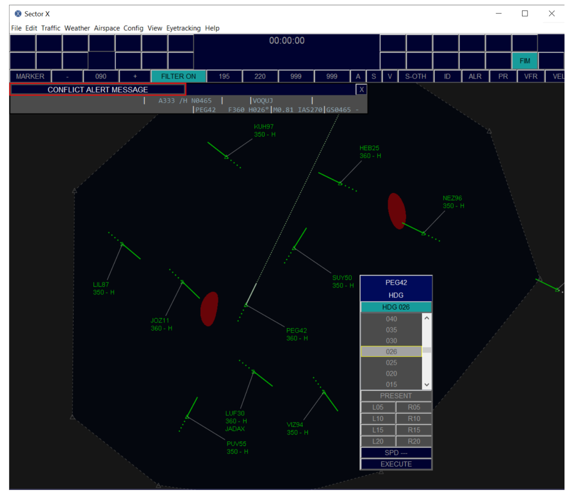


Fig. 4: In SectorX, the HIPS configuration can be activated either through the clearance menu or by long-pressing the heading label item. ATCOs can issue heading and/or speed commands through the clearance menu by specifying exact values and clicking the ‘Execute’ button to implement them.

B. Participants and instructions

Eight TU Delft Aerospace Engineering staff members voluntarily participated in this experiment. All had completed a standardized ATC training course accredited by official organizations (e.g., NLR), ensuring sufficient domain knowledge to interpret CD&R interfaces effectively. This group was selected to balance realism and control—being more informed than laypersons but less biased than professional controllers with entrenched habits [15].

The experiment consisted of two sessions, each focusing on one different decision-making tool. Each session included three phases: briefing, training, and measurement. During the simulation, participants were tasked with (a) transferring and assuming control of aircraft entering or exiting the sector, (b) preventing LoS events, and (c) guiding deviated flights back to their exit waypoints based on previous resolutions.

C. Independent variables

Two independent variables were tested: (a) **configuration**, either HIPS or SSD, and (b) **traffic situation**, low- and high-density traffic, yielding four conditions. A within-participants design was used: each participant completed all conditions.

D. Scenario

The experiment included two scenarios differing in traffic volume, conflict frequency, and route complexity, yielding distinct task difficulty levels across all required activities. All scenarios featured a Short-Term Conflict Alert (STCA).

Authorized licensed use limited to: TU Delft Library. Downloaded on May 06,2026 at 08:28:40 UTC from IEEE Xplore. Restrictions apply.

The simulation for each scenario lasted 20 minutes and ran at 1.5× real-time due to task simplifications.

1) Low Traffic Density (LTD): The LTD scenario contains three routes with two intersection points and five conflicts across FL350 and FL360. These conflicts involve only one aircraft pair at a time, both flying at the same altitude, requiring participants to analyze various traffic patterns at each flight level while identifying and resolving conflicts. During the first 15 minutes, conflict-triggered aircraft entered the airspace at three-minute intervals.

2) High Traffic Density (HTD): The HTD scenario features four routes that intersect at four points, giving rise to a total of seven conflict events distributed across different flight levels. During the first 15 minutes, conflict-triggered aircraft entered the airspace at two-minute intervals.

E. Procedure

During each session, participants used one decision-making tool, either the SSD or the HIPS. Each session lasted approximately 1.5 hours and was scheduled on separate days, with at least a one-day break in between. Participants were introduced to basic ATC tasks and the SectorX simulator. During the training phase, participants managed two traffic scenarios: one characterized by low density and the other by high density. Following a break, they proceeded to the measurement phase, during which they again managed scenarios of both density levels.

To minimize carryover effects, a balanced experimental design was used with varying traffic conditions and tool configurations. Half of the participants started with HIPS, followed by SSD, and vice versa. Participants alternated between LTD and HTD scenarios. Afterward, all completed a survey to provide feedback on each configuration.

F. Control variables

The following elements were kept constant during the entire simulation:

- **Scenario**: All traffic scenarios remained consistent throughout the whole session both for SSD and HIPS configurations.
- **Control style**: Participants could check the conflict status of any aircraft entering the sector by activating configuration at any time. They were restricted to adjusting heading, speed, or both for conflict resolution, with 5-degree heading and 5-knot speed changes via the clearance menu. Altitude clearances were not possible.

G. Dependent measures

The dependent measures in the study were:

- **Safety**: Measured by the number of LoS and STCA events, for both the primary (predefined) or secondary (knock-on) conflicts.
- **Efficiency**: Measured by additional track miles flown and the difference between actual and ideal heading to the exit waypoint.
- **Commands**: Measured by the number and type of commands.
- **Response duration**: Based on the timing of control actions.
- **Workload**: Evaluated using the Rating Scale Mental Effort (RSME) [16].
- **Safety margin**: Measured by comparing the distance at CPA to 5 nm after successful conflict resolution.
- **Survey**: Assessed through a 5-point Likert-scale survey.

H. Hypotheses

First, it was hypothesized that the SSD would lead to a stronger preference for speed adjustments compared to the HIPS (H1), as HIPS requires more interactions for refreshing, while SSD previews both heading and speed in one view. Second and third, it was hypothesized that resolutions made with the HIPS system would be quicker (H2) and also closer to the operational limit (H3), as trajectory visualization in HIPS is more intuitive and simplifies the identification of constraint boundary, while the SSD requires some effort to assess the position of the tip of the controlled aircraft's velocity vector relative to the overlapped velocity obstacles.

IV. RESULTS

Given the small sample size of eight participants, the Wilcoxon signed-rank test was used to analyze differences between conditions, with high and low traffic scenarios analyzed separately. A significance level of $p = 0.05$ was adopted. Results within the threshold are reported with the median value *mdn* for both groups, along with the Z-value, p-value, and the rank-biserial correlation r as the effect size.

A. Safety

With the STCA feature active (triggered 2 minutes before LoS events), no LoS events occurred during the simulation. In the LTD scenario, there were 1 and 2 alerts recorded in HIPS and SSD, respectively. In the HTD scenario, HIPS had 2 alerts compared to 5 for SSD. Most STCA events happened within predefined conflict pairs, with only one observed in the HTD scenario for the HIPS. There were no significant differences observed across the experimental conditions.

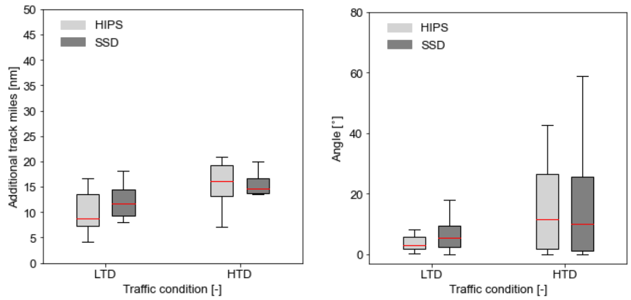
B. Efficiency

Results for efficiency are shown in Fig. 5. The variation in additional track miles for SSD and HIPS is comparable across traffic density. Performance was similar in the HTD scenario, but working with the HIPS display led to better alignment with the exit waypoint than working with the SSD. Statistical results showed that in the LTD scenario, the HIPS ($mdn = 4.182$) and SSD ($mdn = 6.165$) showed a significant difference in angle alignment, with $Z(1) = -2.941$, $p = 0.003$, and $r = -0.509$.

C. Commands

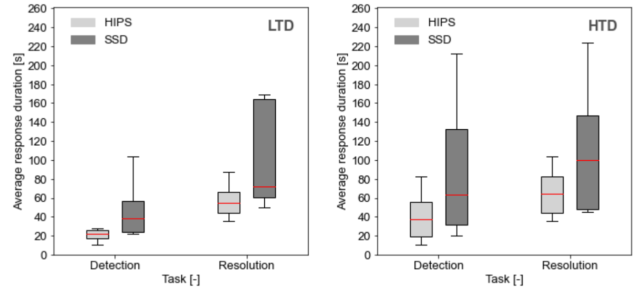
Results for commands are shown in Fig. 6. In the LTD scenario, participants issued more clearances with SSD than HIPS, in both speed and heading commands. In the HTD scenario, SSD still showed higher command issuance, but the difference was less pronounced. Despite these observations, statistical analysis reveals no significant differences under

Authorized licensed use limited to: TU Delft Library. Downloaded on May 06,2026 at 08:28:40 UTC from IEEE Xplore. Restrictions apply.



(a) Additional track miles (b) Angle

Fig. 5: Efficiency performance across traffic conditions.



(a) LTD (b) HTD

Fig. 7: Response duration across traffic conditions.

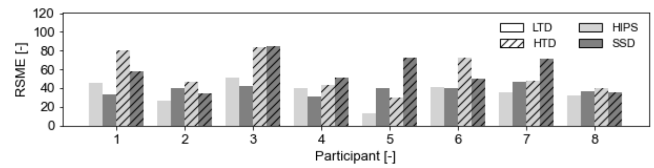
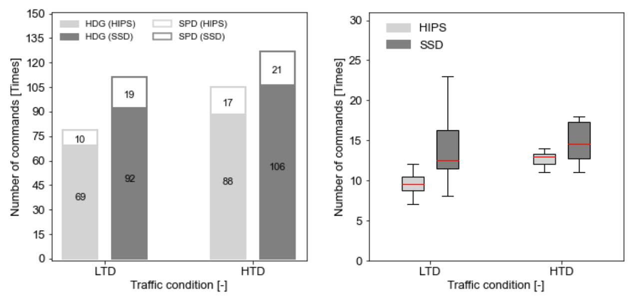


Fig. 8: Workload across traffic conditions.

either traffic scenario. Thus, Hypothesis 1, suggesting SSD's preference for speed commands, is rejected.



(a) Number of commands (b) Distribution

Fig. 6: Commands activities across traffic conditions.

1.811) and the SSD ($mdn = 3.317$) showed a $Z(1) = -2.240$, $p = 0.023$, and $r = -0.889$. Hypothesis 3 is confirmed in the HTD condition.

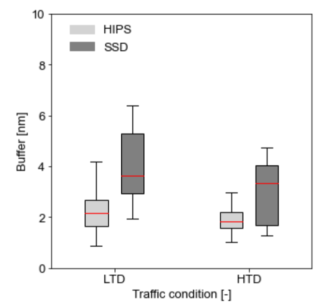


Fig. 9: Safety margin across traffic conditions.

D. Response duration

Results for average response durations are shown in Fig. 7. Working with the SSD led to longer and more variable response times for both tasks across scenarios. A significant effect was found between HIPS and SSD in the LTD scenario for both tasks. In the detection task, the HIPS ($mdn = 22.265$) and SSD ($mdn = 38.680$) showed a significant effect, with $Z(1) = -2.380$, $p = 0.016$, and $r = -0.944$. In the resolution task, the HIPS ($mdn = 55.115$) and SSD ($mdn = 71.945$) also showed a significant effect, with $Z(1) = -2.100$, $p = 0.039$, and $r = -0.833$. Hypothesis 2 was confirmed for both the detection and resolution tasks under low traffic conditions.

E. Workload

Workload results are shown in Fig. 8. Although working with the SSD led to a higher average workload in both scenarios compared to working with the HIPS, no significant difference was observed across traffic conditions.

F. Safety margin

Results for the safety margin are presented in Fig. 9. Working with the SSD led participants to apply a larger separation margin than working with the HIPS, across both traffic conditions. Statistical analysis revealed a significant difference only in the HTD scenario, where the HIPS ($mdn =$

G. Survey

After the experiment, participants assessed how each tool supported aspects of the CD&R task. They found HIPS and SSD similar in identifying conflict pairs, both sharing a limitation in expediting traffic (e.g., optimizing the recovery). However, SSD was considered more effective in identifying resolution options, understanding conflict states, avoiding secondary conflicts, and managing deviated aircraft, while the HIPS was preferred for assessing conflict urgency and severity and selecting solutions with less deviation. Despite these perceived differences, objective results did not always align with the perceived advantages of SSD over HIPS.

V. DISCUSSION

This paper investigated the comparative performance of two CD&R tools by examining how their distinct visual structures encode control-relevant elements and influence

Authorized licensed use limited to: TU Delft Library. Downloaded on May 06,2026 at 08:28:40 UTC from IEEE Xplore. Restrictions apply.

operator behavior. Although some hypotheses were not confirmed due to a lack of significant differences, the analysis provided valuable insights into each tool's strengths and challenges in supporting CD&R tasks.

Both tools offer key advantages as decision-support systems for complex conflict tasks, as shown by positive survey results. Also, common challenges were identified. For example, some participants noted that *"unneeded HIPS areas could be quite distracting,"* while SSD participants suggested, *"Do not show conflicts with aircraft behind the selected aircraft."*, highlighting the need for a proper filtering mechanism for both systems. For post-resolution recovery, HIPS participants found *"resuming original speed or direct-to exit point to be a bit difficult,"* while SSD users struggled to *"keep track of deviating aircraft,"* emphasizing the same need for better operational efficiency.

The distinct design features of HIPS and SSD result in noticeable performance differences under low-density traffic. Specifically, HIPS resulted in fewer commands, shorter response times, and smaller margins, whereas SSD showed the opposite pattern. Additionally, the HIPS group consistently demonstrated greater consistency in these variables across traffic conditions, suggesting it may serve as a more intuitive tool for operators of varying experience. However, as traffic becomes more complex, the observed differences between the tools diminish, suggesting that operators rely more on the functional meaning of interface elements than on their specific visual form.

The subjectively reported preferences for SSD were not supported by objective data. The more tentative decision-making observed under SSD may be attributed to its dense, centralized visual layout, which demands a steeper learning curve and precise visual checks. While SSD provides a flexible representation of heading and speed, enabling exploration of more optimal options, it only showed a non-significant trend towards fewer speed commands and more conservative responses. The increased margins observed appeared to be a strategy for managing cognitive load, without a significant increase in workload as traffic density rose. Some participants even reported perceiving smaller margins with SSD. This apparent contradiction may stem from visual factors: in SSD, a one-degree difference in heading appears minor when visualized as a short velocity vector near the aircraft, whereas the same deviation becomes more noticeable in HIPS due to the projection of tracklines over greater distances. As a result, HIPS's visual design promoted more decisive and efficiency-oriented responses, as reflected in reduced margin usage and better angle alignment. Survey data also showed that participants found HIPS more effective for assessing conflict urgency. These trends were further supported by observed prioritization, where some participants resolved only the immediate conflict, deferring others for greater efficiency.

VI. Conclusion and Future Work

This paper compared two decision-support tools (i.e., HIPS and SSD) for conflict detection and resolution in air traffic control by analyzing how each interface encodes control-relevant elements and affects operator behavior. The contrasting results highlight fundamental differences: HIPS, with its intuitive projection-based visualization, led to quicker actions and consistent behavior, while the SSD, with its centralized design displaying heading and speed solutions, introduced complexity that affected decision consistency but also provided more flexibility. The differences between the two tools are more pronounced in low-traffic conditions, suggesting that selected interfaces did influence user behavior, particularly when tasks are less constrained. These findings emphasize that user behavior and tool effectiveness vary based on the operational context, and interfaces should be designed to accommodate shifts in decision-making patterns, especially in more dynamic environments like future traffic control systems.

References

[1] ICAO, "2016–2030 Global Air Navigation Plan," Tech. Rep. Doc 9750, Fifth Edition, International Civil Aviation Organization, Montreal, Canada, 2016.

[2] SESAR Joint Undertaking, "European ATM Master Plan — Making Europe the Most Efficient and Environmentally Friendly Sky to Fly in the World," Tech. Rep. 2025 Edition, Publications Office of the European Union, Luxembourg, 2024.

[3] SESAR Joint Undertaking, "Automation in Air Traffic Management," Tech. Rep. MG-02-20-699-EN-N, Publications Office of the European Union, Luxembourg, 2020.

[4] C. Westin, C. Borst, and B. Hilburn, "Strategic conformance: Overcoming acceptance issues of decision aiding automation?," *IEEE Transactions on Human-Machine Systems*, vol. 46, no. 1, pp. 41–52, 2015.

[5] C. Borst, J. M. Flach, and J. Ellerbroek, "Beyond ecological interface design: Lessons from concerns and misconceptions," *IEEE Transactions on Human-Machine Systems*, vol. 45, no. 2, pp. 164–175, 2014.

[6] B. Strauch, "Ironies of automation: Still unresolved after all these years," *IEEE Transactions on Human-Machine Systems*, vol. 48, no. 5, pp. 419–433, 2017.

[7] R. Ehrmanntraut, *Full automation of air traffic management in high complexity airspace*. PhD thesis, TU Dresden, 2010.

[8] G. de Rooij, A. Tisza, C. Borst, M. M. van Paassen, and M. Mulder, "Towards human-automation teamwork in shared en-route air traffic control: Task analysis," in *IEEE 3rd International Conference on Human-Machine Systems (ICHMS)*, pp. 1–7, IEEE, 2022.

[9] C. Meckiff and P. Gibbs, "PHARE Highly Interactive Problem Solver," Tech. Rep. EEC Report 273/94, EUROCONTROL, Brussels, Belgium, 1994.

[10] N. Durand, J.-B. Gotteland, N. Matton, L. Bortolotti, and M. Sandt, "Understanding and overcoming horizontal separation complexity in air traffic control: an expert/novice comparison," *Cognition, Technology & Work*, vol. 23, no. 3, pp. 481–496, 2021.

[11] R. E. Klomp, *Solution space concept for trajectory-based air traffic control: An ecological approach*. PhD thesis, TU Delft, 2023.

[12] EUROCONTROL, "LORD adds speed and flexibility to decisions for Maastricht controllers," *Skyway*, no. 79, pp. 54–56, 2024.

[13] I. Wilson, "PHARE Advanced Tools Project Final Report," Tech. Rep. Doc 98-70-18/1, EUROCONTROL, Brussels, Belgium, 1999.

[14] M. M. van Paassen, C. Borst, J. Ellerbroek, M. Mulder, and J. M. Flach, "Ecological interface design for vehicle locomotion control," *IEEE Transactions on Human-Machine Systems*, vol. 48, no. 5, pp. 541–555, 2018.

[15] M. M. van Paassen, C. Borst, M. Mulder, G. de Rooij, F. Dijkstra, and A. B. Tisza, "On the appropriate participant expertise for display evaluation studies," in *22nd International Symposium on Aviation Psychology (ISAP)*, 2023.

[16] F. R. H. Zijlstra, *Efficiency in work behaviour: A design approach for modern tools.* PhD thesis, TU Delft, 1995.

Authorized licensed use limited to: TU Delft Library. Downloaded on May 06,2026 at 08:28:40 UTC from IEEE Xplore. Restrictions apply.