



E-UI Validation Report

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MAHALO

MODERN ATM VIA HUMAN / AUTOMATION LEARNING OPTIMISATION

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Abstract

This document is the *E-UI Validation Report*, deliverable D4.2 of the MAHALO project. This report reflects the output of MAHALO Task 4.3 and builds on the earlier Tasks 4.1 and 4.2, and D4.1 *E-UI Design Document and Demonstrator*, which presented the design choices and implementation details of the interface SectorX to be used in MAHALO experiments. D4.1 also included a video demonstrating the interface.

This report describes a test of the E-UI SectorX simulator with the purpose of validating that the interactions, functions, and output of SectorX are aligned with the requirements for ML integration and subsequent large scale human-in-the-loop simulations. A secondary aim of this report was to evaluate eye tracking as an input tool to the ML system, and as a method for objective performance assessment. The validation was conducted with an experienced enroute ATCO solving conflicts in example scenarios. Interaction data and conflict solutions were recorded and logged automatically by SectorX. In addition, eye-tracking data was collected using Tobii Pro Glasses 2.

Results of task 4.3 testing confirmed SectorX functionality and simulation realism, validated data logging protocols and formats, and demonstrated the integrated use of eye tracking and output data. Lessons were drawn regarding ATCO strategies, data logging, and eye tracking integration, for subsequent WP6 experimental design.

This report does not describe a full validation of the MAHALO concept, which has been already described in *D2.2 – Concept report* and will be further detailed in the forthcoming *D6.1 – Experimental design document*.

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1. Introduction

This document is the *E-UI Validation Report*, deliverable D4.2 of the MAHALO project. As shown in figure 1.1, WP4 activities centre on development and validation of the project's Ecological User Interface (E-UI). WP4 is situated within MAHALO as an output of WP2 conceptual definition, an input to the ML / E-UI integration efforts of WP5, and interactively with development of the project's ML model (WP3).

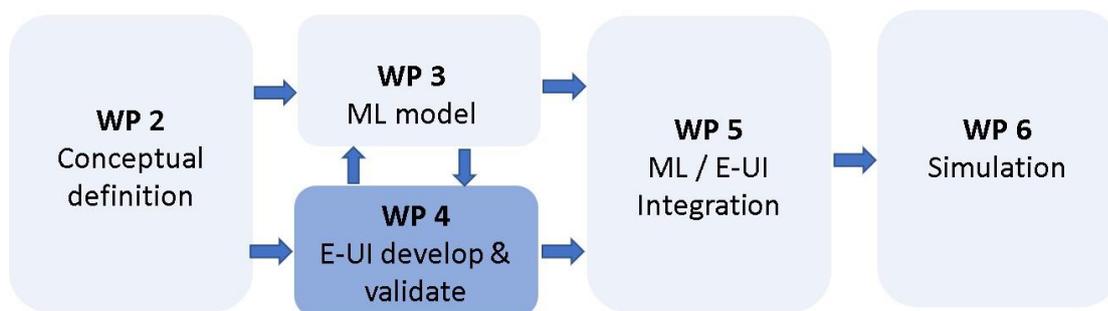


Fig. 1.1. WP4 within the MAHALO technical work package flow.

This report reflects the output of MAHALO Task 4.3 and builds on the earlier Task 4.1 and 4.2, and D4.1 *E-UI Design Document and Demonstrator*, which presented the design choices and implementation details of the interface to be used in MAHALO experiments. D4.1 also included a video demonstrating the interface. Also, this report does not describe a full validation of the MAHALO concept, which has been already described in *D2.2 – Concept report* and will be further detailed in the forthcoming *D6.1 – Experimental design document*.

The MAHALO project has two high-level goals. The first is to develop a hybrid machine learning capability for detecting and resolving air traffic control conflicts. The second goal is to assess the impact of such a capability in terms of human performance, focusing on such constructs as mental workload, acceptance, trust, reliance, and human – machine system performance. To achieve these two ambitious goals, the MAHALO project must start from a clear specification of its concept of operations, simulation scenarios, and protocols for testing and data analysis.

The purpose of this report is to ascertain that the interactions, functions, and output of SectorX are aligned with the requirements for ML integration and subsequent simulations. Results from this first simulation were useful for updating the experimental design in D2.2. However, the study was not developed according to the experimental design in D2.2, nor was that the intention. As such, resolution advisories and the independent variables of conformance and transparency were not included in this

validation. The experimental protocols intended to be used in upcoming simulation were also not used in this simulation.

1.1 Report structure

The remainder of this report consists of:

- Chapter 2—an overview of the SectorX E-UI and its functionality
- Chapter 3—methods used for validation testing
- Chapter 4—validation results, regarding SectorX functionality, data recording framework, and eye tracking integration
- Chapter 5—conclusions, including lessons learnt, and guidance for subsequent WP6 experimental design

2. E-UI - SectorX

The Ecological User Interface (E-UI) for the MAHALO project is based on SectorX, a Java-based medium fidelity ATC research simulator developed by the TU Delft. SectorX flight dynamics conform to BADA performance models. For the purposes of MAHALO, SectorX has been adapted to realistically mimic the Maastricht Upper Area Control (MUAC) controller working position (CWP), including STCA, MTCA, and VERA capabilities. Details of the E-UI, including control functionality and design considerations, can be found in the previous report in this series, D4.1 *E-UI Design*.



Fig. 2.1. SectorX Plan view Display.



Fig. 2.2. SectorX control menus.

SectorX consists of separate Editor (creating scenarios), Simulator (running scenarios), and Viewer (replaying scenarios) modules. Menu-driven scenario creation allows flexibility in creating airspace and traffic scenarios, which are then assembled into a playlist of individual scenarios. As a research simulator, SectorX is configured for extensive data logging. State- and event logs are timestamp written to XML text files, which can be easily handled in post processing. Excerpts of state- and event data files, obtained from validation testing, can be found in Annex B. SectorX permits runtime reconfiguration of nearly 100 parameters, related to the simulation dynamics, playback, airspace and aircraft parameters, HMI features, and ancillary data collection hooks (e.g., for ISA workload measurements). These configurable parameters are presented in Annex C.

3. Method

3.1 Validation plan

The objective of this study was to determine if the interactions, functions, and output of SectorX are aligned with the requirements for ML integration and subsequent simulations. Input to this study was therefore requirements set up by the ML systems, specifically the Supervised Learning (SL) and Reinforcement learning (RL) modules, and the experimental design. These requirements were then assessed in relation to user interactions and functions of the system, and the output.

As a requirement for future experiments (WP5 and WP6), SectorX must allow participants to work and control en route traffic as an air traffic controller. The control requirements of SectorX are outlined in D4.1 *E-UI Design*. At a higher level, the control task consisted of the following subtasks:

- Assuming control over incoming aircraft;
- Clearing aircraft to target altitudes;
- Detecting and resolving conflicts;
- Clearing aircraft to destinations; and
- Transferring aircraft to adjacent sector.

The validation considered all these subtasks. The validation exercise comprised a simulation in SectorX.

3.2 Validation objectives

Table 1 summarises the validation objectives and requirements for SectorX. In the validation simulation, only requirements 1-7, and 9, were tested. The subsequent requirements will be validated as part of the integration of the ML systems and E-UI in WP5 and the first simulation with novices.

Table 1 SectorX validation objectives (requirements)

<i>Requirement</i>	<i>Description</i>
1	SectorX must allow for ‘assuming’ control of aircraft (Conformance pre-study and Main experiment).
2	SectorX must allow for clearing aircraft to target altitudes (Conformance pre-study and Main experiment).
3	SectorX must allow for detecting conflicts and resolving them using heading and altitude (Conformance pre-study and Main experiment).

4	SectorX must allow for clearing aircraft to their destinations (i.e. exit waypoints) (Conformance pre-study and Main experiment).
5	SectorX must allow for transferring aircraft to the next sector (Conformance pre-study and Main experiment).
6	SectorX must output data detailing the conflict resolution implemented by the user (Conformance pre-study).
7	SectorX must output conflict specific data relating to time, control inputs, traffic states, and pixel data (Conformance pre-study).
8	SectorX must be able to provide resolution advisories generate by the ML models (Main experiment). The user should be able to accept or reject these advisories.
9	SectorX must be able to provide explanations pertaining to the domain transparency (Main experiment).
10	SectorX must be able to provide explanations pertaining to the agent transparency and conformance rationale (Main experiment).
11	SectorX should output aircraft track/altitude deviation (nm/ft) (Main experiment).
12	SectorX should output time when advisory is accepted/rejected (Main experiment).
13	It would be good if SectorX could collect subjective measures.

Because MAHALO aims to develop a ML Conflict detection and resolution (CD&R) system, specific focus was given to the CD&R interactions and functions: heading and altitude. Speed and route interventions were not considered in this validation study. Speed is an infrequently used resolution type in en-route control given the marginal effect on aircraft separation at tactical control. The ability for a ML system to solve conflicts with route changes is more complex than heading and altitude and were therefore not considered at this stage. Moreover, as a first step of several, a route change also results in an initial heading or altitude change. A subsequent step in a route change comprises a clearance back to the aircraft flight plan. The control task requirements of SectorX can be summarised in:

Requirement 1: SectorX must allow for ‘assuming’ control of aircraft.

Requirement 2: SectorX must allow for clearing aircraft to target altitudes.

Requirement 3: SectorX must allow for detecting conflicts and resolving them using heading and altitude.

Requirement 4. SectorX must allow for clearing aircraft to their destinations (i.e. exit waypoints).

Requirement 5. SectorX must allow for transferring aircraft to the next sector.

One objective of MAHALO is to build a CD&R advisory system that can recommend solutions that are either conformal (i.e., the system recommends personalized conflict resolutions) or optimal (with no regard for the individual's preferences). To do so, a hybrid architecture is proposed, building on a combination of SL and RL approaches. Three models will be developed: a Personalized prediction model; a Group prediction model; and an Optimized prediction model.

The Personalized prediction model builds on an SL approach using Convolutional Neural Network (CNN) and pixel data. The output of the SL model will be conformal advisories; advisories that are based on how a specific individual has previously solved similar situations. The generation of conformal solutions requires that the SL model can be trained with data (i.e., conflict solutions) generated from one individual. Each individual participating in the MAHALO experiments will be required to first generate data that can be used to train that individual's SL model. The Group prediction model will be based on the dominant (average) solution strategies across all Personalized prediction models within a given data set (i.e., experimental run). A RL approach will be used to create an optimized prediction model. In contrast to the SL modules, of which there will be many, there will only be one RL module. The RL module does not require training data from an individual.

The MAHALO experimental design builds on a two-step data collection procedure: 1) the Conformance pre-test, and 2) the Main experiment. In this procedure, data from the first step is used to train the Personalized and Group SL models. Since SectorX is used as the simulator, SectorX must output data on how participants solve conflicts that can be used as the training set for the SL models.

Requirement 6: SectorX must output data detailing the conflict resolution implemented by the user.

To classify an individual's solution of a conflict, detailed information about the solution must be output by SectorX, including when the solution was implemented, what aircraft was chosen (or if both), the resolution type, direction, and exact value. A more comprehensive list is provided in Figure 3.1. The traffic states of all other aircraft are needed as their position and trajectories may affect the solutions applicable to the conflict of interest. Output on traffic states are also needed as input to the RL model and for replaying scenarios, which is useful for subsequent manual analyses.

Time keeping

Time when conflict is detected
Time when interaction is taken to solve conflict

Control inputs

Aircraft choice; Resolution type (i.e. heading, speed, altitude); Resolution direction (i.e. left, right, climb, descend); Directional value

Traffic states

Callsign, Type, BADA performance envelope, 2D position (x,y), current & cleared altitude (FL), IAS, TAS, GS, Mach, heading, track, flight plan, sector entry & exit points @ sim. radar update interval (e.g., every 10 sec)

Pixel data

PNG snapshots of radar screen & solution space @ sim. time of clearance

Fig. 3.1. SectorX data output requirements.

Requirement 7: SectorX must output conflict specific data relating to time, control inputs, traffic states, and pixel data.

The output from the SL models will be used to generate both personalized and group conformal advisories in the main experiment. In addition, the RL model will recommend optimal solutions to conflicts. As such, a requirement of SectorX is that advisories, generated by both the SL and RL models, can be implemented and visualised. This could, for example, be achieved by visualising a new heading drawn from the aircraft symbol, highlight a recommended altitude in the label, or provide a separate prompt with the resolution advisory in plain text. Moreover, the user must be able to accept or reject these advisories, regardless of how they are presented (e.g. varying with transparency). For this, an option is to use a separate dialogue window allowing the user to act on a recommended advisory.

Requirement 8: SectorX must be able to provide resolution advisories generate by the ML models. The user should be able to accept or reject these advisories.

In addition, MAHALO intends to explore the transparency of the ML advisories in the Main experiments. There are two transparency levels: domain transparency and agent transparency in terms of *Conformance rationale*. The domain transparency refers to the information gathered and analysed by the advisory system when generating a particular recommendation. The domain transparency visualises the work domain constraints that shape the space for available solutions. The intention is to use the Solution Space Diagram as a visualisation of domain transparency to associate resolution advisories.

Requirement 9: SectorX must be able to provide explanations pertaining to the domain transparency.

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Conformance rationale refers to the ML advisory system's ability to afford transparency by explaining why a specific recommended solution is either conformal or nonconformal. The generation of a conformance rationale requires a connection to the ML models created. SectorX is not required to generate the conformance rationale, but must be able to visualize it in text or graphics.

Requirement 10: SectorX must be able to provide explanations pertaining to the agent transparency and conformance rationale.

For the main experiment, the experimental plan requires that we can measure participants' performance objectively in terms of how far from track/altitude an aircraft deviates (e.g., the aircraft that is given a new heading or altitude).

Requirement 11: SectorX should output aircraft track/altitude deviation (nm/ft) (Main experiment).

Another measure is response time, the time taken for a participant to respond to a conflict resolution advisory generated by the system.

Requirement 12: SectorX should output time when advisory is accepted/rejected (Main experiment)

Moreover, subjective measures will be collected for better understanding the individual's reaction to scenarios and resolution advisories. This may include understanding of an advisory; agreement with an advisory; trust; and workload/difficulty. While these measures can be collected using paper and pen, or another screen, a good solution would be to integrate it with SectorX.

Requirement 13: It would be good if SectorX could collect subjective measures.

3.3 Validation assumptions

SectorX meets the requirements and assumptions for MAHALO set out in the D2.1 Integrated State of the Art Report. Specifically, SectorX provides a suitable working environment for an executive controller in single person operations. The software is particularly suited for tactical control in the en-route domain. SectorX incorporates capabilities beyond those used for these validation trials. For example, extended CD&R algorithms are in development, to permit automated altitude resolutions and route modifications. Again, these capabilities were disabled for validation testing of the baseline SectorX.

Certain other simplifying assumptions were made, for reasons of the validation testing. For example:

- wind and adverse weather were not modelled.
- Datalink and pilot response delays were disregarded

3.4 Validation method

One ATCO with more than 5 years of area and terminal control experience from Stockholm Area Control Centre (ACC), Sweden, participated in the pilot study. The purpose of the validation did not cover participant performance, which is why one participant was judged acceptable for this validation. However, an experienced controller as participant was deemed appropriate given the knowledge based required for interacting with SectorX and solving the CD&R task. This made it possible to derive some lessons from the ATCO's performance.

The participant received a brief introduction to SectorX and the eye tracking system. This was followed by a consensual approval to participate in the study. Data collection started with a calibration of the eye tracking system. The participant then received instructions on how to use SectorX and solve conflicts. Instructions were provided to solve tasks as if on a normal working day (except that solutions were limited to 2D—i.e., heading only). The participant then played the eleven scenarios. The participant was encouraged to try out different functions and solutions in SectorX. The entire data collection took roughly 40 minutes, of which 30 minutes was spent solving the scenarios. A questionnaire was administered after the simulation.

3.5 Validation platform description

SectorX was run on a portable Windows Surface Pro Tablet (Intel Core i5) connected to an external 28" display (ASUS PB287Q) with a resolution of 1920 x 1080. The user interacted with the system by means of mouse and keyboard.

The wearable Tobii Pro Glasses 2 eye tracker was used to record the participant's eye movements. Tobii Pro Glasses 2 uses a pupil centre corneal reflection technique, recording eye point of gaze (EPOG) at a 1/50s rate (50Hz). Small flashes on the glasses frame illuminate the eye with Infrared light to increase pupil and corneal reflections. Small cameras record the reflection (glint) on the cornea and pupil. Algorithms then triangulate EPOG and overlays it as a red circle on the video recorded of the scene the user is facing (i.e., where attention is directed). EPOG data were analysed in the Tobii Pro Lab software.

3.6 Reference scenario description

The validation was restricted to the use of a reference scenario, representing the current day ATC CD&R task. The validation did not test the solutions proposed and developed by the MAHALO project (specifically the ML models) and therefore did not include any solution scenarios (testing the proposed solutions). In MAHALO, the reference scenarios refer to scenarios that do not vary conformance or transparency of resolution advisories.

Eleven simple scenarios were used in the data collection. Ten of these only contained two aircraft in conflict, at varying conflict geometries but at level flight. These were to be solved only using horizontal resolutions. One scenario loosely based on MUAC airspace contained two conflict situations as shown in Figure 3.2. For solving the conflicts in this scenario, the participant could also use altitude resolution. All scenarios made use of a generic sector. The ten scenarios with only two aircraft had a squared sector.

There were several reasons for using simple scenarios. We wanted to simplify the analysis of the solutions implemented, making sure that the simulator collects the data we need to output from SectorX and use as input to the ML models. We have also made a decision to restrict the conflict types to only two aircraft – to simplify creating the ML model and limit the amount of training data required (i.e., fewer situations are needed).

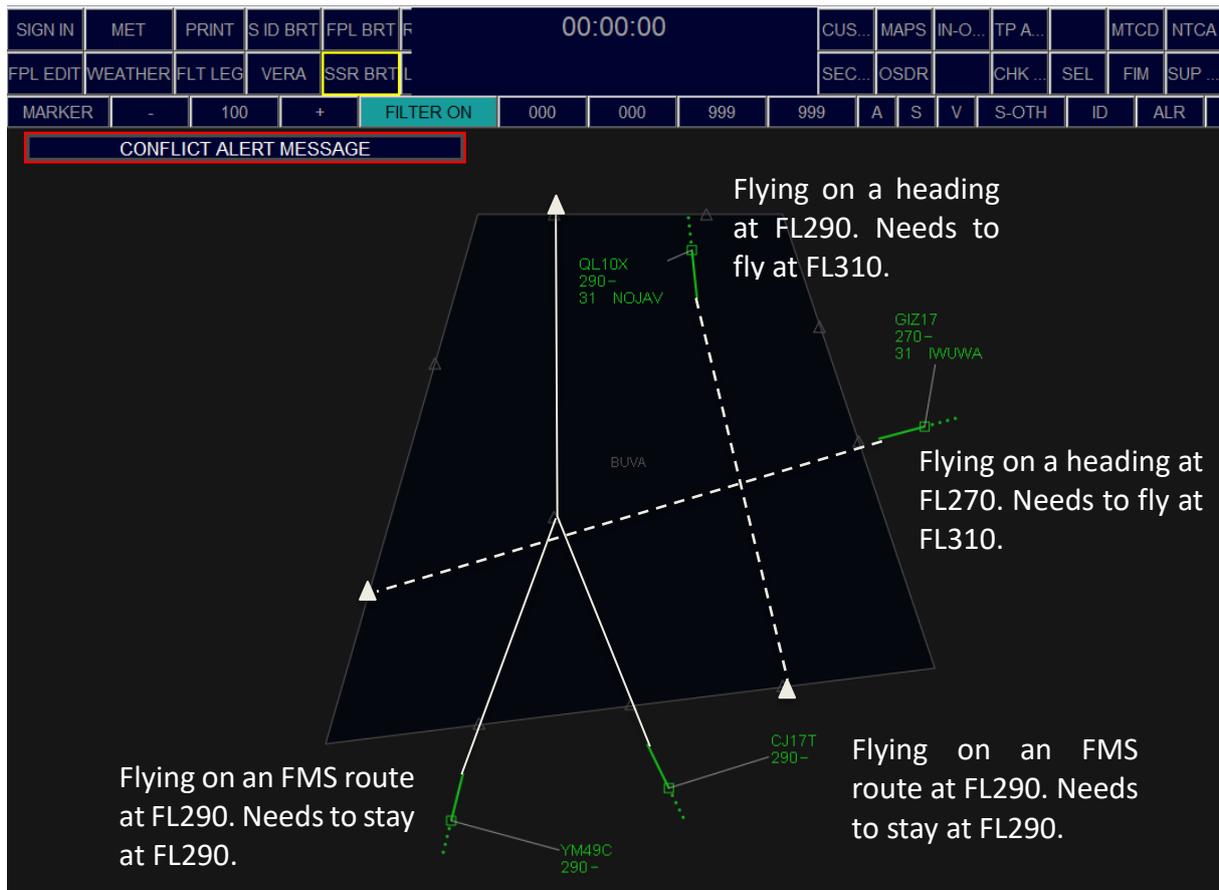


Fig. 3.2. SectorX data output requirements

4. Validation results

Figure 4.1 shows a simulation run, in which the participant is solving the scenario with two conflicts, using both heading and altitude. The simulation ran smoothly with no disruptions or technical problems.



Fig. 4.1. Image from validation simulation.

Table 2 provides a summary of the validation results mapped against the validation objectives listed in Table 1. Each requirement is discussed in more detail in subsequent subsections.

Table 2 SectorX validation results

Requirement	Result
1 - 'Assuming' control of aircraft	Requirement fulfilled – participant able to assume control of traffic by interacting with the label.

2 - Clearing aircraft to target altitudes	Requirement fulfilled – participant able to change the flight level of aircraft and clear aircraft to their target altitudes by interacting with the label (CFL).
3 - Detecting conflicts and resolving them using heading and altitude	Requirement fulfilled – participant detected all scripted conflicts, in all scenarios, and solved them using heading (scenario 1-10) or altitude (scenario with two conflicts).
4 - Clearing aircraft to their destinations (i.e. exit waypoints)	Requirement fulfilled – participant able to clear aircraft to their exit waypoints by means of heading or using the 'direct to' function in the label
5 - Transferring aircraft to the next sector	Requirement fulfilled – participant able to transfer aircraft to the next sector by interacting with the label
6 - Output data detailing the conflict resolution implemented by the user	Requirement fulfilled – The StateLog and EventLog files provide information of what the participant did, and when, to solve conflicts.
7 - Output conflict specific data relating to time, control inputs, traffic states, and pixel data	Requirement fulfilled – the StateLog and EventLog files provide detailed information about traffic states and the participant's interactions with traffic. Together with a screenshot of the SSD at the time a solution (to a scripted conflict of interest), the logdata provide all the necessary output from SectorX required to populate the training data for the SL models.
8 - Provide resolution advisories generate by the ML models	Requirement not fulfilled – resolution advisories not yet implemented.
9 - Provide explanations pertaining to the domain transparency	Requirement fulfilled – participant able to explore the SSD tool for determining which solution strategy to use.
10 - Provide explanations pertaining to the agent transparency and conformance rationale	Requirement not fulfilled – agent transparency not yet implemented in system, although popup window for text-based information exist and can be used to provide text-based explanations.
11 - Output aircraft track/altitude deviation (nm/ft)	Requirement not fulfilled – functionality for determining track/altitude deviation not yet implemented.
12 - Output time when advisory is accepted/rejected	Requirement not fulfilled – functionality for accepting/rejecting advisories not yet implemented.
13 - Collect subjective measures	Requirement not fulfilled – functionality for collecting subjective measures not yet implemented.

4.1 SectorX functionality (Requirement 1-5; 9)

The participant noted that the SectorX interface was similar to that of the TOPSKY, which the participant currently uses at Stockholm ACC. The VERA tool was new to the participant, but judged similar to the SEP-tool in TOPSKY. There were no major issues with the simulation, although the participant would have liked to use speed clearances to solve conflicts with aircraft merging towards the same exit waypoint. Further, some waypoint names consisted of four—rather than the standard five—letters.

The participant successfully controlled the traffic and solved the conflicts in all scenarios. All five requirements pertaining to the control task, were achieved:

- The participant assumed control of traffic by interacting with the label (*Requirement 1*).
- The participant could change the flight level of aircraft and clear aircraft to their target altitudes by interacting with the label (CFL) (*Requirement 2*).
- The participant detected all scripted conflicts, in all scenarios, and solved them using heading (scenario 1-10) or altitude (scenario with two conflicts) (*Requirement 3*). When solving conflicts, the participant used the VERA tool to probe the distance from the aircraft current position to the assigned exit point (COPX) and to probe the distance between two aircraft. For example, if both aircraft were to exit the sector though the same waypoint, the aircraft furthest away from the waypoint was turned behind the other. When probing the distance between two aircraft, the participant used the VERA tool to determine which strategy to use for solving the conflict depending on the conflict geometry and closest point of approach between the aircraft (provided in NM by the VERA tool). In addition, the participant was allowed to explore the SSD tool for determining which solution strategy to use (*Requirement 9*). The participant thought the SSD was easy to work with and provided insight to the conflict geometry between aircraft.
- The participant could clear aircraft to their exit waypoints by means of heading or using the 'direct to' function in the label (*Requirement 4*).
- The participant could also transfer aircraft to the next sector by interacting with the label (*Requirement 5*).

4.2 Data recording framework (SectorX output, Requirement 6-7)

The collected data can be replayed in the SectorX Viewer. Figure 4.2 shows replay of the scenario including two conflicts (note that Figure 4.1 shows the starting point of the same scenario, for comparison). The conflict between QL10X and GIZ17 has been solved with a change of heading (left turn) for both aircraft. The conflict between YM49C and CJ17T has been solved by altitude, having CJ17T climb to FL310. Both aircraft have also been given Direct clearances to their exit point (EGAXU for both).



Fig. 4.2. Replay of scenario with two conflicts in SectorX Viewer mode. The trajectory changes (where the red history lines turn) indicate where and when the conflicts were solved using heading.

The StateLog and EventLog files provide details of what the participant did, and when, as part of solving conflicts. Together with a screenshot of the SSD at the time a solution (to a scripted conflict of interest), the logdata provide all the necessary output from SectorX required to populate the training data for the SL models (*Requirement 6 and 7*). SectorX logged all traffic states from a scenario, at each traffic update (the simulation used a rate of once every five seconds). All aircraft states are logged every update in a **Statelog.xml** file. An example is provided below. All system interactions (events: e.g., label click and drags, clearances/commands to flights, etc.) are logged when issued (time stamped) in the **Eventlog.xml** file. The two XML files are stored in a **logdata** folder.

The **EventLog** is used to find out which aircraft (callsign) received a flight command at what time (scenarioTime). Then, the **StateLog** is used to retrieve the controlled and observed aircraft states within the radar update that best fits the scenarioTime at which the flight command was given.

Here is an example with relevant information in logdata highlighted in bold. For the scenario in figure 4.2, the **EventLog** at 'scenarioTime' 50.2 s show that the participant ('agent = human') implemented ('flightEventType = flightCommand') a heading of 165 degrees for aircraft QL10X.

```
<event eventType="flightEvent" flightEventType="flightCommand"
agent="human" callsign="QL10X" flightCommandMode="heading" head
ing="165.0" scenarioTime="50.205784" realTime="25.102892"/>
```

In the StateLog, the change to the aircraft QL10X can be observed by comparing timestamps before and after the heading change was implemented. Below, only the **StateLog** for QL10X is shown. The heading before the change (scenarioTime =45.171566) was 174.0, which corresponds with the **targetHeading** for that aircraft. At a later update (scenarioTime =55.211795), the heading has changed to 169.41144). Note also that the 'targetHeading' has change (165.0), the current 'bankAngle' (-18.0), and current 'track' change (171.70572). Because it takes time for the aircraft to reach the new heading, the heading changes gradually over time until the new heading is stabilized (at scenarioTime 90.35886).

```
<state realTime="22.585783" scenarioTime="45.171566" performanceScore="81.54768">
<aircraft callsign="QL10X" radarStatus="active" icao="A388" isSelected="true" isAutomated="false" caution="false" conflict="false" controlled="false" ownNavigation="true" flightState="assumed" label_x="-99.452194" label_y="-10.452847" x="8.60936" y="20.421099" altitude="29000.0" heading="174.0" track="174.0" bankAngle="0.0" acceleration="0.0" gs="387.1662" tas="387.1662" ias="250.0" rocd="0.0" mach="0.6540285" ias_min="215.68039" ias_max="340.0" tas_min="336.77472" tas_max="513.8347" targetAltitude="29000.0" targetHeading="174.0" targetIas="250.0"/>

<state realTime="27.605898" scenarioTime="55.211796" performanceScore="81.17502">
<aircraft callsign="QL10X" radarStatus="active" icao="A388" isSelected="false" isAutomated="false" caution="false" conflict="false" controlled="false" ownNavigation="false" flightState="assumed" label_x="-99.452194" label_y="-10.452847" x="8.743618" y="19.349907" altitude="29000.0" heading="169.41144" track="171.70572" bankAngle="-18.0" acceleration="0.0" gs="387.1662" tas="387.1662" ias="250.0" rocd="0.0" mach="0.6540285" ias_min="215.68039" ias_max="340.0" tas_min="336.77472" tas_max="513.8347" targetAltitude="29000.0" targetHeading="165.0" targetIas="250.0"/>
```

The logdata can be used to access required timing information when action is taken to solve the conflict, aircraft choice, resolution type, resolution direction, and directional value (see figure 3.1 and Requirement 7). However, time when conflict is detected can only partly be extracted from the **EventLog**. For example, an indication of conflict detection can be extracted from data on the use of the VERA tool – when two aircraft are selected to provide a time estimate of when the closest point of approach will be reached, and if this is less than the required separation criteria (e.g., 5nm horizontally and 1000ft vertically).

Below is an example of an **EventLog** where the altitude (flight level) of aircraft CJ17T was changed to FL310.

```
<event eventType="flightEvent" flightEventType="flightCommand" agent="human" callsign="CJ17T" flightCommandMode="altitude" altitude="31000.0" scenarioTime="80.66174" realTime="40.33087"/>
```

The SSD for the aircraft can be shown in the replay of the scenario using the SectorX viewer mode. From the replay, the SSD for the aircraft controlled can be captured and saved for export, together with the logdata, for use as input to the training set for the SL models. Figure 4.3 shows the SSD of QL10X, where the magenta-colored line represents the track towards the exit point NOJAV. The bolder green line indicates the current heading (left of magenta track) and the thin green line indicates the cleared heading of 165 degrees (right of magenta track). Figure 4.4 shows an identical SSD, situated at the bottom left of the interface. This SSD is easier to extract from the interface because it is always shown at the same position, whereas the SSD shown around the aircraft is shown at the position of the aircraft (which changes over time).

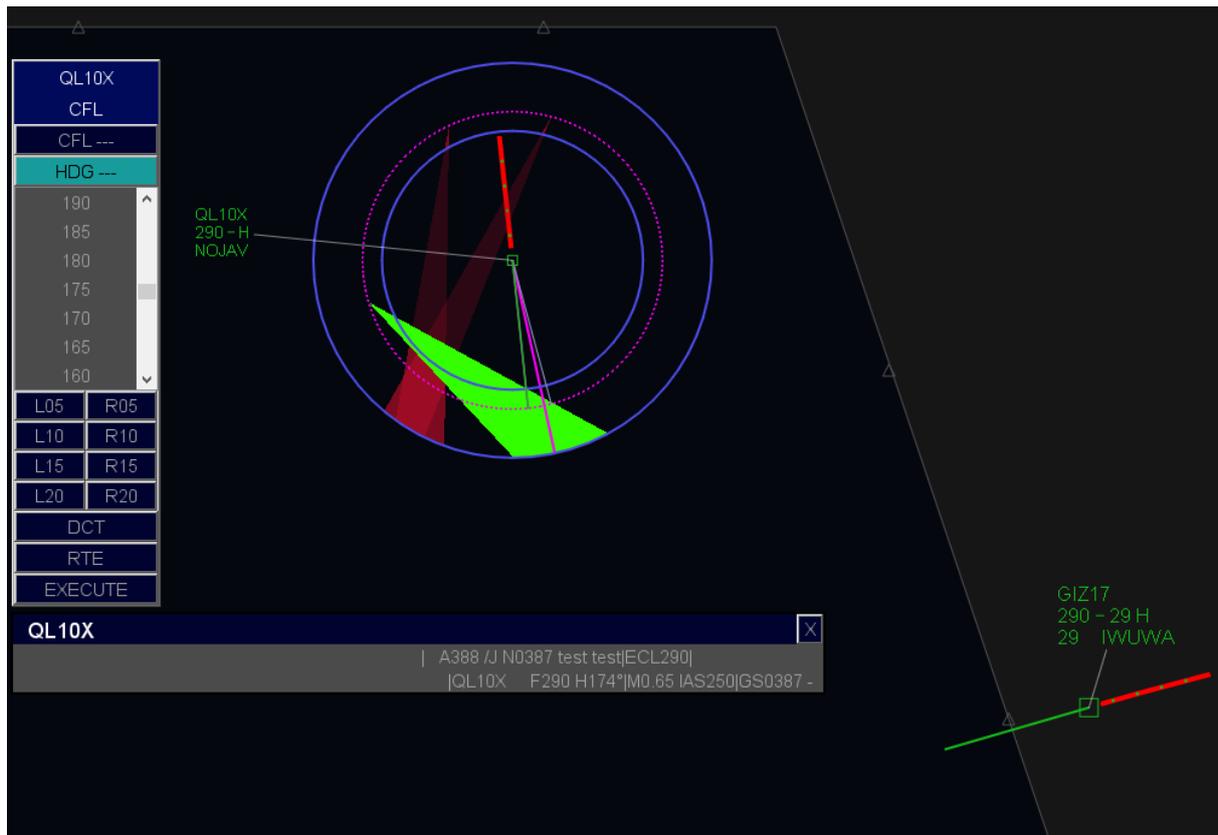


Fig. 4.3. Screen capture at time when QL10X is given a new heading of 165 degrees. The green triangle indicates the restricted zone of GIZ17, for which the heading was given to avoid a separation loss.

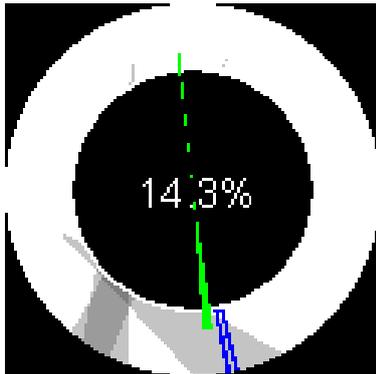


Fig. 4.4. SSD for QL10X shown in bottom left corner of the interface. This image of the SSD can be used as input by the ML systems to capture the conflict state of a selected aircraft and resolution implemented at specific time (*Requirement 7*).

4.3 Questionnaire

The participant was generally positive about SectorX and thought that it provided a realistic working environment, and was both useful and easy to use. The participant was missing some functionalities from the real-life system, including the SEP-tool (in TOPSKY) and MTCD visualisation that provide information on the closest point of approach along the route. Scenarios were rated too easy and slightly short, not allowing for clearing aircraft back on their route after the conflict was solved.

4.4 Eye tracking data

The heatmap in Figure 4.5 depicts the participant's visual attention in terms of absolute fixation count when solving the conflict between QL10X and GIZ17. The heatmap covers a period of 25 seconds. The heatmap indicates that the participant, during this time window, mainly focused on the two aircraft and their labels.

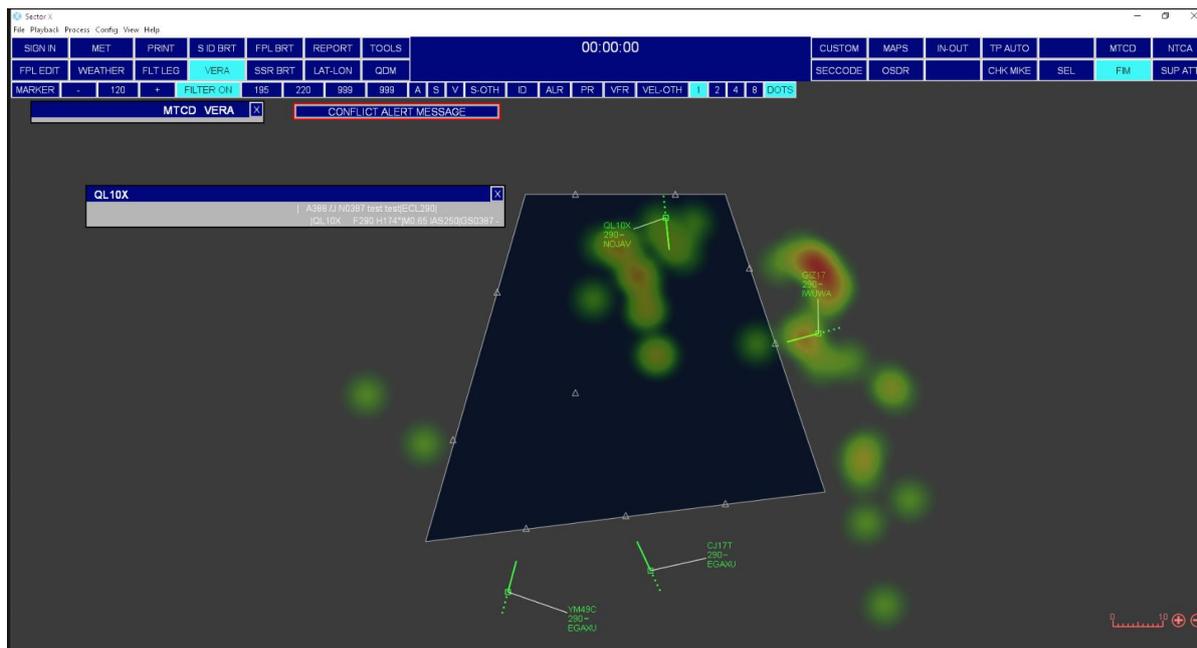


Fig. 4.5. Heat map depicting participant’s visual attention when solving the conflict between QL10X and GIZ17.

There are several fixations (indicated by green circles) in areas away from the aircraft. These can better be explained by replaying the video with the EPOG overlay. The replay shows that the participant interacted with the label to open the drop-down menu, for example to change the heading, or to explore the distance from one aircraft to its exit point. Figure 4.6 show two frames, one second apart, where the participant has selected the drop-down menu from the label. The EPOG overlay, and previous saccades, are shown by the red/white circle and red lines, respectively. The participant here selected the drop-down menu and used the Direct to function to instruct the aircraft to go directly to its exit point. The participant fixated the exit waypoint before using the mouse to drag and point the “Direct to cross” (at the end of the yellow dotted line) to the waypoint. EPOG then returned back to the drop-down menu as the participant fixated and clicked “EXECUTE”. By analysing the participant’s gaze and first fixations of the two aircraft involved in a conflict, an estimate of the time of conflict detection can be made with better accuracy than the logdata alone.

The eye tracking system showed a high level of spatial accuracy. Calibration offset tests (where known and indicated EPOG are compared) were not performed. However, from certain events (e.g., When a menu item should have been fixated) it was possible to confirm current EPOG. In this case, point of gaze seemed accurate to within about 1cm.

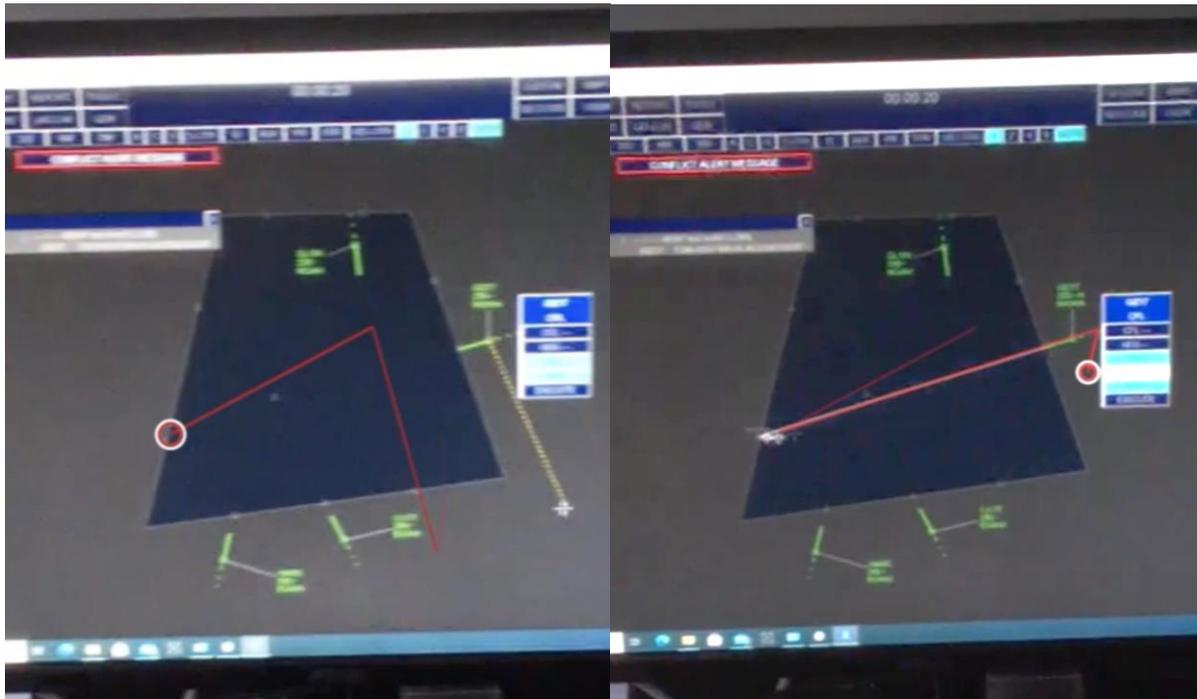


Fig. 4.6. Screen captures with low resolution of video replay with gaze overlay at 1 second interval (from analysing eye tracking data in Tobii Pro Lab) showing the participant's eye point of gaze when using the VERA tool to probe distance-to-exit-waypoint.

5. Conclusions

Out of the requirements listed in Table 1, requirements 1-7 and 9 were confirmed in the validation simulation. Requirements 8 and 10-13 remain to be validated as part of the main experiment, following ML integration with SectorX.

5.1 Lessons learnt

5.1.1 Interface and simulation realism

Survey responses (presented in Annex A) were collected on realism of the simulation, including:

- Enroute traffic scenarios;
- Air-ground interactions; and
- Aircraft performance;

Feedback was also collected on conformance of the UI per se, with current day operational systems, including:

- Look and feel of the UI; and
- Control menu functionalities.

Both areas were positively judged by the validation test participant (again, a fully licensed, experienced Swedish air traffic controller). The experimental UI (based loosely on MUAC specs) conformed well with the TOPSKY system, as currently used in Sweden. This was an expected, but nonetheless encouraging, result. Questionnaire responses indicate that SectorX is suitable as a simulation platform in upcoming MAHALO experiments and that little training is likely to be required for familiarising participants, who are experienced controllers, with the interface and its interactions and functions. Valuable feedback was gained on the timing and ending of scenarios. The participant did not think scenarios needed to start earlier, but end a bit later to accommodate clearances back on route.

5.1.2 ATCO control strategies

Although participant performance in SectorX was not an objective, results provided valuable lessons to be considered in the experimental design and ML design. It is possible, in a pending conflict between two aircraft, that a controller would choose to turn only one of the two involved aircraft. However, the test participant often turned both aircraft, seemingly splitting the costs of diversion.

Also, validation runs highlighted that human ATCOs might solve problems in ways that might sometimes differ from an optimised approach. For example:

- **Rough solutions**-- The validation test participant tended to use round headings. Whereas a machine might choose an optimal heading of 289 or 292 degrees, an ATCO might choose 290.
- **Progressive clearances and corrections**—after initially turning an aircraft at a greater-than-required heading, an ATCO might monitor the diversion, then issue a follow-on clearance back toward the destination. For example, after turning an aircraft 20 degrees right, and monitoring for increasing distance between the conflict pair, the ATCO might turn the aircraft 10 degrees left, on a rough heading back toward initial destination.
- **Joint clearances**—rather than turning a single aircraft e.g., 20 degrees off-course, a human ATCO might (our test validation participant did) turn each aircraft 10 degrees off course. This, in effect, shares the cost of diversion

An implication of the above for the ML system, is that the ability to consider solutions where the states of both aircraft involved are changed (e.g., by adjusting the heading of both aircraft 10 degrees). At a first step, the SL system should be able to learn this type of conflict solutions. At a second step, the SL system should be able to suggest such solutions, conformal to the individual participant.

Notice how some of these control strategies might be, mathematically speaking, sub-optimal. For example, an optimal solution might involve turning (one or both) aircraft to achieve a total 8.7 degrees of diversion between an aircraft pair. A controller might, however, choose to turn each aircraft a conservative 10 degrees, monitor, issue follow-on clearances to turn back 5 degrees, etc. Flight time and fuel burn differences are minimal, but clearance time can be two- to three times greater.

Notice how Supervised Learning (SL) and Reinforcement Learning (RL) models would handle such human-in-the-loop data differently. An SL system learning from the human data would learn to mimic the ATCO's (suboptimal) behaviour of joint clearances, progressive clearances, and rough solutions. An RL system, however, would begin from higher level conflict resolution goals (e.g., minimise aircraft flight time to next waypoint), and could therefore choose to turn an aircraft exactly 8-, rather than a rough 10 degrees.

5.1.3 Eye tracking

A secondary aim of validation testing was to evaluate eye tracking, in terms of spatial resolution (accuracy), and integration with the E-UI. Validation testing collected EPOG data which was later transformed for this report into visualisations of saccades (i.e., traces between successive fixation points) and fixation heat maps (capturing fixation location and duration).

As discussed in section 4.3, based on visual inspection of EPOG track, the team was able to confirm a fairly high spatial accuracy of the eye tracking data. That is, based on examining where we knew the participant to be looking (from e.g., menu selections), eye point of gaze seemed to generally be within 1 cm of target. This level of spatial accuracy, while not sufficient to determine, for example, at which line a controller was looking, would allow us to determine the general region of fixation, to the level of clearance menu, or traffic region, or individual aircraft. This can serve as a useful measure of general visual attention, as a potential input to ML supervised learning. For example, attention guidance techniques can be used to determine if a person has detected a conflict and possibly the strategy considered to solve a conflict, such as which aircraft to act on.

A benefit of using eye tracking is that it allows for better determining when conflicts are detected. This is important for determining when to provide the participant with an advisory on how to solve a particular conflict. For an advisory to be valuable, we assume that the advisory must be provided at

the latest just before an individual typically solves a conflict, and ideally around the time a conflict is detected. The time taken between a conflict is detected and when a solution is implemented comprise the time window during which the individual can gather and process information to determine which strategy to use for solving the situation.

5.1.4 Data logging

A chief aim of validation testing was to confirm that the E-UI could reliably capture timestamped events and traffic state, in a way that can serve as input to ML development. Post validation examination of XML data logs confirmed that data capture aircraft trajectory and control input events to permit graphical replay and serve as input to eventual ML modules (Requirement 6-7).

5.2 Input to experimental design

5.2.1 General guidance

Refining experimental design for subsequent modelling and simulations will be an iterative process. Based on the reported validation trials, however, we can already present an initial list of items to help guide this design. These items generally fall out into the areas of traffic scenarios, dependent measures, and overall simulation design.

- **General traffic scenario characteristics**—generic en route traffic scenarios of short (about 120 sec) duration will present a limited number of potential conflicts
- **Simulation realism**—SectorX, as configured for validation trials, and using generic traffic scenarios, seems to accommodate semi-novice participants, while providing sufficient operational realism for professional ATCOs.
- **Conflict Geometry**—literature shows that closure angles impact resolution difficulty, and strategy consensus among controllers, in resolving conflicts. For upcoming TUD student trials we should explore a variety of conflict geometries to cover the majority of conflict types: e.g., head-on versus oblique vs right angles, climbing and descending aircraft etc.
- **Peripheral ‘noise’ aircraft**—although we will only consider two-aircraft conflicts, there must also be peripheral aircraft’ as part of the traffic scenario. Otherwise, the scenarios will likely be too trivial. Designing scenarios will involve also creating sufficient numbers and appropriate trajectories, of these noise aircraft.
- **Eye tracking integration**—eye tracking should be integrated on a medium level of granularity. Validation trials demonstrated a spatial accuracy of about 1cm for eye point of gaze. This is certainly sufficient to allow real-time identification of onscreen ‘region of interest’ to within a few centimetres.

5.2.1 Potential issues

MAHALO work to date has revealed not only specific lessons for experimental design, but some general issues that we intend to monitor for potential impact on the eventual simulation methodology. These include the following (as with the guidance items of section 5.2.1, this list is considered a living document, that is subject to update)

- **Appropriate traffic levels**— The difficulty of CD&R, and resolving conflicts, varies with traffic level and other complexity factors such as conflict geometry. Experimental design requires that traffic levels be calibrated so as to be neither too trivial, nor overwhelmingly difficult. This will be done by informally surveying members of LFV, but also through iterative pre-testing and tweaking.
- **Appropriate traffic complexity levels**—similarly, iterative testing and tweaking will be required to establish conflict scenarios that are neither too easy, nor too hard.
- **Sufficient data set size**—ML famously required enormous amounts of training data. The team is currently considering different approaches to obtaining a sufficiently large training data set.
- **Precise timing of system solutions**— an advisory that is presented too late (after the controller has already devised a solution) provides no benefit. Also, an advisory that comes too early (before the controller has even considered the conflict) can force extra workload. Refining the timing of system advisories will require iterative testing and tweaking.

Acronyms

ACC	Area Control Centre
AI	Artificial Intelligence
ATCO	Air Traffic Controller
BADA	Base of Aircraft Data
CD	Conflict Detection
CD&R	Conflict Detection and Resolution
CR	Conflict Resolution
CWP	Controller Working Position
E-UI	Ecological User Interface
EPOG	Eye Point of Gaze
FL	Flight Level
GS	Ground speed
IAS	Indicated Airspeed
LFV	Luftfartsverket
MAHALO	Modernising ATM via Human-Automation Learning Optimisation
ML	Machine Learning
MTCA	Medium Term Conflict Alert
MUAC	Maastricht Upper Airspace Centre
PVD	Plan View Display
RL	Reinforcement Learning
RT	Radio telephony
SSD	Solution Space Diagram
STCA	Short Term Conflict Alert
SL	Supervised Learning
TAS	True Airspeed
UI	User Interface
VERA	Verification of Separation and Resolution Advisory
XML	Extensible Markup Language

Annex A. Participant Survey

Participant’s responses are indicated by symbol

Aircraft flightpaths were realistic (given fixed altitudes, and zero wind).

Disagree strongly Disagree slightly Neutral Agree slightly Agree strongly

The UI (user interface) was easy to use.

Disagree strongly Disagree slightly Neutral Agree slightly Agree strongly

Explanation: In the real interface, I often use a vectorline that show the course and position 1 minute ahead of time. I use this to determine if the aircraft is following the route towards the exit point. I missed this function in the interface.

The SSD portion of the UI was easy to use.

Disagree strongly Disagree slightly Neutral Agree slightly Agree strongly

The UI was useful.

Disagree strongly Disagree slightly Neutral Agree slightly Agree strongly

The SSD was useful.

Disagree strongly Disagree slightly Neutral Agree slightly Agree strongly

The UI is similar to what I currently use (given datalink interface).

Disagree strongly Disagree slightly Neutral Agree slightly Agree strongly

The UI lacks some useful features of my usual interface.

Disagree strongly Disagree slightly Neutral Agree slightly Agree strongly

Explain: trajectory prediction line e.g. 1 minute ahead. MTCO function that shown where conflicts will occur according to flightplan (in red and yellow). This information was not very well provided in the interface.

The UI made certain clearances difficult.

<input type="checkbox"/>				
Disagree strongly	Disagree slightly	Neutral	Agree slightly	Agree strongly

The VERA tool performed correctly.

<input type="checkbox"/>				
Disagree strongly	Disagree slightly	Neutral	Agree slightly	Agree strongly

Explain: Missing point along route where CPA is. VERA provided minutes only.

The scenarios were trivial.

<input type="checkbox"/>				
Disagree strongly	Disagree slightly	Neutral	Agree slightly	Agree strongly

Explain: Scenario with two conflicts was a bit tricky.

The scenarios were too short.

<input type="checkbox"/>				
Disagree strongly	Disagree slightly	Neutral	Agree slightly	Agree strongly

Explain: Some scenarios were a little bit short and did not allow time for giving clearance back to exit point.

I had enough time to familiarize with the UI.

<input type="checkbox"/>				
Disagree strongly	Disagree slightly	Neutral	Agree slightly	Agree strongly

Annex B. State and event data logging

B1. Event log (excerpted)

```

<aircraft id="FET27" type="1" x="-0.06521773" y="-21.249998" heading="359.8956" ias="250.0"
altitude="29000.0" departure="" destination="" copx="AKON" target_altitude="29000.0" automated="false"
flightState="assumed">
<route>
<points/>
</route>
</aircraft>
<aircraft id="DF72S" type="1" x="25.043476" y="-10.92391" heading="305.67282" ias="250.0"
altitude="29000.0" departure="" destination="" copx="TWIN" target_altitude="29000.0" automated="false"
flightState="assumed">
<event eventType="hmiEvent" hmiEventType="hmiInitializationEvent" date="2021/05/05" time="16:24:51"/>
<event eventType="flightEvent" flightEventType="flightLabelSelection" callsign="DF72S"
flightLabelSelectionMode="selected" scenarioTime="3.6279259" realTime="1.8139629"/>
<event eventType="flightEvent" flightEventType="flightSelection" callsign="DF72S"
flightSelectionMode="selected" scenarioTime="3.659567" realTime="1.8297836"/>
<event eventType="flightEvent" flightEventType="flightLabelSelection" callsign="DF72S"
flightLabelSelectionMode="idle" scenarioTime="4.784893" realTime="2.3924465"/>
<event eventType="flightEvent" flightEventType="flightLabelSelection" callsign="DF72S"
flightLabelSelectionMode="selected" scenarioTime="5.665288" realTime="2.832644"/>
<event eventType="flightEvent" flightEventType="flightSelection" callsign="DF72S"
flightSelectionMode="selected" scenarioTime="5.7061872" realTime="2.8530936"/>
<mouse mouseEventType="pressed" scenarioTime="7.3571453" realTime="3.6785727" x="1426" y="347"/>
<mouse mouseEventType="released" scenarioTime="7.51238" realTime="3.75619" x="1426" y="347"/>
<event eventType="hmiEvent" hmiEventType="hmiDialogEvent" id="muacClearanceMenu" open="true"
scenarioTime="7.574156" realTime="3.787078"/>
<event eventType="flightEvent" flightEventType="flightLabelSelection" callsign="DF72S"
flightLabelSelectionMode="idle" scenarioTime="13.71263" realTime="6.856315"/>
<event eventType="hmiEvent" hmiEventType="hmiDialogEvent" id="muacClearanceMenu" open="false"
scenarioTime="17.149723" realTime="8.574862"/>
<mouse mouseEventType="released" scenarioTime="17.310297" realTime="8.6551485" x="1110" y="497"/>
<mouse mouseEventType="pressed" scenarioTime="17.783615" realTime="8.891808" x="1116" y="480"/>
<mouse mouseEventType="released" scenarioTime="17.981749" realTime="8.990874" x="1116" y="480"/>
<event eventType="flightEvent" flightEventType="flightLabelSelection" callsign="DF72S"
flightLabelSelectionMode="selected" scenarioTime="18.74896" realTime="9.37448"/>
<event eventType="flightEvent" flightEventType="flightSelection" callsign="DF72S"
flightSelectionMode="selected" scenarioTime="18.78888" realTime="9.39444"/>
<mouse mouseEventType="pressed" scenarioTime="19.351536" realTime="9.675768" x="1360" y="375"/>
<mouse mouseEventType="released" scenarioTime="19.549643" realTime="9.774821" x="1360" y="375"/>
<event eventType="hmiEvent" hmiEventType="hmiDialogEvent" id="muacAssumeMenu" open="true"

```

B2. State log (excerpted)

<states>

<state realTime="2.500941" scenarioTime="5.001882" performanceScore="100.0">

```
<aircraft callsign="FET27" radarStatus="active" type_name="none" isSelected="false"
isAutomated="false" caution="false" conflict="false" controlled="false" ownNavigation="true"
flightState="assumed" label_x="99.99983" label_y="0.18221338" x="-0.06619792" y="-20.712067"
altitude="29000.0" heading="359.8956" track="359.8956" bankAngle="0.0" acceleration="0.0"
gs="387.1662" tas="387.1662" ias="250.0" rocd="0.0" mach="0.6540285" ias_min="200.0"
ias_max="290.0" tas_min="313.3818" tas_max="444.45007" targetAltitude="29000.0"
targetHeading="359.8956" targetIas="250.0"/>
```

```
<aircraft callsign="DF72S" radarStatus="active" type_name="none" isSelected="true"
isAutomated="false" caution="false" conflict="false" controlled="false" ownNavigation="true"
flightState="assumed" label_x="58.315594" label_y="81.23602" x="24.60648" y="-10.610211"
altitude="29000.0" heading="305.67282" track="305.67282" bankAngle="0.0" acceleration="0.0"
gs="387.1662" tas="387.1662" ias="250.0" rocd="0.0" mach="0.6540285" ias_min="200.0"
ias_max="290.0" tas_min="313.3818" tas_max="444.45007" targetAltitude="29000.0"
targetHeading="305.67282" targetIas="250.0"/>
```

</state>

<state realTime="5.003569" scenarioTime="10.007138" performanceScore="100.0">

```
<aircraft callsign="FET27" radarStatus="active" type_name="none" isSelected="false"
isAutomated="false" caution="false" conflict="false" controlled="false" ownNavigation="true"
flightState="assumed" label_x="99.99983" label_y="0.18221338" x="-0.06717876" y="-20.17377"
altitude="29000.0" heading="359.8956" track="359.8956" bankAngle="0.0" acceleration="0.0"
gs="387.1662" tas="387.1662" ias="250.0" rocd="0.0" mach="0.6540285" ias_min="200.0"
ias_max="290.0" tas_min="313.3818" tas_max="444.45007" targetAltitude="29000.0"
targetHeading="359.8956" targetIas="250.0"/>
```

```
<aircraft callsign="DF72S" radarStatus="active" type_name="none" isSelected="true"
isAutomated="false" caution="false" conflict="false" controlled="false" ownNavigation="true"
flightState="assumed" label_x="58.315594" label_y="81.23602" x="24.16919" y="-10.296301"
altitude="29000.0" heading="305.67282" track="305.67282" bankAngle="0.0" acceleration="0.0"
gs="387.1662" tas="387.1662" ias="250.0" rocd="0.0" mach="0.6540285" ias_min="200.0"
ias_max="290.0" tas_min="313.3818" tas_max="444.45007" targetAltitude="29000.0"
targetHeading="305.67282" targetIas="250.0"/>
```

B3. Heading change events, from validation test scenarios

scenario	real time	acft	alt (FL)	ias (kts)	hdg	event
1	0.0	FET27	290	250	360	initial
	0.0	DF72S	290	250	270	initial
	12.1	DF72S	290	250	265	heading change
	21.8	FET27	290	250	355	heading change
	34.3	DF72S	290	250	265	heading change
2	0.0	FET27	290	250	360	initial
	0.0	DF72S	290	250	298	initial
	26.1	DF72S	290	250	295	heading change
	30.5	FET27	290	250	355	heading change
	52.1	FET27	290	250	350	heading change
	59.6	DF72S	290	250	285	heading change
3	0.0	FET27	290	250	360	initial
	0.0	DF72S	290	250	090	initial
	15.1	DF72S	290	250	095	heading change
	25.9	FET27	290	250	010	heading change
	61.1	FET27	290	250	005	heading change
4	0.0	FET27	290	250	360	initial
	0.0	DF72S	290	250	090	initial
	15.0	DF72S	290	250	095	heading change
	25.9	FET27	290	250	010	heading change
	61.1	FET27	290	250	005	heading change
5	0.0	FET27	290	250	360	initial
	0.0	DF72S	290	250	024	initial
	51.1	DF72S	290	250	085	heading change
6	0.0	FET27	290	250	360	initial
	0.0	DF72S	290	250	180	initial
	29.9	FET27	290	250	010	heading change
	34.7	DF72S	290	250	190	heading change
7	0.0	FET27	290	250	360	initial
	0.0	DF72S	290	250	215	initial
	14.8	DF72S	290	250	220	heading change
	20.3	FET27	290	250	005	heading change



8	0.0	FET27	290	250	360	initial
	0.0	DF72S	290	250	226	initial
	24.8	FET27	290	250	355	heading change
	30.9	DF72S	290	250	220	heading change
9	0.0	FET27	290	250	360	initial
	0.0	DF72S	290	250	306	initial
	17.9	FET27	290	250	355	heading change
	23.8	DF72S	290	250	295	heading change
	40.4	FET27	290	250	350	heading change
10	0.0	FET27	290	250	360	initial
	0.0	DF72S	290	250	062	initial
	32.0	FET27	290	250	010	heading change
	42.3	DF72S	290	250	070	heading change
	92.6	FET27	290	250	000	heading change

Annex C. SectorX configuration parameters

Category	Parameter
Viewport	Logging
Viewport	Grid snap
Viewport	Timeslider
Viewport	Ruler
Viewport	Magnifier
Viewport	Show viewer information
Viewport	Show info bar
Viewport	Show time bar
Viewport	Show frame rate
Viewport	Show TU Delft copyright
Viewport	Show grid in Editor
Viewport	Show info bar in Editor
Viewport	Show time bar in Editor
Viewport	Enable zooming [CTRL + mouse wheel]
Sector	Airports
Sector	Airport name
Sector	Airport name on mouseover
Sector	Traffic route
Sector	Sector
Sector	Separation areas
Sector	Waypoints
Sector	Waypoint name
Sector	Waypoint name on mouseover
Sector	Fill waypoint symbols
Sector	Waypoint zone
Sector	Georegions
Sector	Geoborder line stipple
Sector	Other georegion line stipple
Aircraft	Control aircraft outside sector
Aircraft	Oncourse indication
Aircraft	Allow dragging aircraft
Aircraft	Protected Zone
Aircraft	Half Protected Zone
Aircraft	Speed vector
Aircraft	Aircraft relative speeds
Aircraft	Aircraft label outline
Aircraft	Drag aircraft labels

Aircraft	Aircraft history dots
Aircraft	Aircraft flight trails
Aircraft	Aircraft trajectories
Aircraft	Aircraft trajectories when selected
Aircraft	Show SSD complexity when aircraft selected
Aircraft	Show SSD in playback mode when controlled
Aircraft	Show SSD complexity in playback mode when controlled
Aircraft	Compass
Aircraft	Aircraft icons
Aircraft	Aircraft track
Aircraft	Aircraft track to COPX
Aircraft	Aircraft relative tracks
Aircraft	Aircraft relative track color coding
Aircraft	Cutoff aircraft track at sector boundary
Aircraft	Trajectory Space Representation (only in MUAC style)
Aircraft	Solution Space Diagram (SSD)
Aircraft	Aircraft SSD COPX marker
Aircraft	SSD conflict zones
Aircraft	SSD speed envelope
Aircraft	Show aircraft SSD outside of sector
Aircraft	SSD cut conflict zone at minimum speed
Aircraft	Aircraft labels
Aircraft	Concise aircraft label
Aircraft	Expand aircraft label on hover
Aircraft	Shade/color CFL menu blocked altitudes (only in MUAC style)
Aircraft	Shade/color HDG menu blocked headings (only in MUAC style)
Automation	Opportunistic automated heading solver, prioritizing COPX
Automation	Printing automation messages to console
Automation	Automatically assume control over automated aircraft transferred to me when they are in the sector
Automation	Show automation notifications in flight labels and aircraft blips
Automation	Show automation message dialog in simulator mode
Alerting	Conflict detection (color + sound)
Alerting	Use CFL in vertical STCA prediction
Alerting	Timeslider alert zones
Complexity	Exclude TOC in SSD complexity
Complexity	Exclude conflict zones of aircraft outside sector
Separation Monitor	Separation Monitor
Simulator	Enable altitude dimension
Simulator	Enable speed control
Simulator	Automatically advance to next scenarios in playlist without requiring human input

Simulator	Force all traffic to be automated upon loading a scenario in simulator mode
Simulator	Decouple scenario duration and traffic update
Simulator	Pause/play button to stop/start simulator
CDU	Enable pages
CDU	Error sound
ISA workload	ISA Rating
ISA workload	ISA Alert Sound
ISA workload	Show previous rating
Conflict rating	Conflict rating dialog
HMI	Show score
HMI	Use difficulty rating (after scenario run)
HMI	Direct Manipulation
HMI	Automatic transfer of control (TOC)
TET	Enable Task Assistant
Wind Field	Show wind visualization