Lesson Learned: Design and Perception of Single Controller Operations Support Tools

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Abstract. Skilled labour shortage is a well-known current issue throughout western hemisphere. It affects air navigation service providers as well in recruitment of future air traffic controllers. One promising solution is a highly-automated enhanced support system enabling a deployment of one single air traffic controller per sector instead of two for a standard layout. However, automation can be problematic if it is impossible to establish trust for humans into technology.

This paper presents design and interaction methods of validated support tools and functions during a validation campaign of single controller operations, the conduct of the validation itself and mainly the results regarding design and perception of air traffic controllers for support tools.

A validation was carried out with a total of seven air traffic controllers with twenty-one human-in-the-loop real-time simulation validation runs in 2023 to assess design, perception and usability of the tools proposed for single controller operations and to provide a proof of concept for the feasibility of the SCO concept and the system as a whole. A selection of seven support tools were evaluated under different traffic loads and defined frame conditions including a variety of typical controller tasks and events in air traffic control.

The results presented in this paper helped to rank and select support tools and functions, to detect possible improvements in design, interaction methods, human-machine information exchange and distribution of tasks in order to empower a human single controller to perform safe, efficient and sustainable operations in a team with a digital supporting environment.

Keywords: Single Controller Operations, Trust in Automation, Human Machine Teaming, Sonification.

1 Introduction

1.1 Motivation

Air traffic levels are predicted to continuing increase worldwide [1]. At some crowded airspaces though, already today the maximum capacity cannot be made available at all times, in particular due to a lack of air traffic controllers [2 - 4].

The skills required of an air traffic controller are manifold, so it cannot be assumed that this deficit can be compensated by hiring and training additional. Demographic change in western hemisphere [5] and other countries will impair this even further. One possible solution is to reduce the number of planed controllers per control sector from two at present to one in future (single controller operation, SCO). The main research question addressed in this paper is which conditions and support tools are sufficient to enable SCO and how their interfaces to team up with humans should be designed.

1.2 Theoretical Background

Within the German Aerospace Center (DLR)-project *The Individual and Automated Air Traffic* (DIAL) the development of a concept and the construction of a prototype to demonstrate a single controller workstation for upper airspace was conducted [6 - 7]. This involves a transition from the current system with one Radar Controller (Executive Controller) and one Planning Controller (Coordinator) to a single controller (SC) working together with a digital controller (DC). The results of a validation campaign of an intermediate step with one SC and enhanced support tools regarding subjective feedback from Air Traffic Controllers (ATCOs) collected through standard questionnaires and individual responses on design and perception are presented in this paper.

The underlying concept is presented in [6] and [7]. As expounded there SCO in en-route air traffic control (ATC) is still not widely researched except considering the more comprehensive concept of flight-centric ATC, which includes a single controller to be responsible for several aircraft throughout the flight time and is more comparable to the role of a pure Radar Controller [8 - 10]. Therefore, the focus of support tools is different (e.g. no consideration of coordination) and additional requirements relating to situational awareness must also be considered.

The SCO concept assumes a task shift in a way that the SC will take over task from Radar Controller (e.g. conflict solution) and from Planning Controller (e.g. coordination) whereas other tasks are automated (e.g. initial call). A major assumption is a higher coverage of Controller-Pilot-Data-Link-Communication (CPDLC) equipped aircraft [6] A wide range of different support tools in terms of design and functionality were proposed to support air traffic controllers as SC in the SCO concept presented in [6] and [7]. Support tools used in the validation campaign are summarised in **Table 1**. A short overview of each tool is given below. A detailed description can be found in [6], [7] and [11].

Table 1. Overview of support tools and characteristics

tool	can be switched on/off	configurable
Attention Guidance (AG)	No	No
Auto-Coordination	No	No
Boundary Arrival Task Manager (BATMAN)	No	Yes
Dynamic Heatmap (DHM)	Yes	Yes
Sonification	Yes	No
Trajectory Generation and Advisory Tool (TraGAT)	works on request only	No

Attention Guidance. Attention Guidance (AG) is a support tool that is supposed to enhances the situation awareness of ATCOs by promptly alerting them to critical flight events on the radar display. The tool is designed to provide three levels of visual alerts that communicate the urgency of events. Level 1 is indicated by a rectangular box around the flight label, Level 2 by a filled circle without a border, and Level 3, the highest alert, by a filled circle with a border. The activation of AG is sequential, starting with Level 1 and progressing to Level 2 and eventually Level 3 as the intensity of the identified event increases. For instance, if there is a conflict between two aircraft with a time to resolution less than five minutes, Level 1 is triggered on both aircraft labels. As the time to resolution decreases, the alert level progresses to Level 2 and eventually Level 3. The tool provides timely attention to important events and even recognizes ATCO interventions by acknowledging through disabling AG. In essence, AG seamlessly integrates into the operational workflow with enhanced situation awareness and effective decision-making in fast-paced ATC environment. [7]

BATMAN. The Boundary Arrival Task Manager should support ATCOs when handling aircraft to fulfil handover conditions. The GUI shows the flights listed on a timeline by their handover time to the adjacent sectors, and is intended to be an additional tool for the radar display. If handover constraints like flight levels or time separations are not met, BATMAN can give advisories and can check for possible conflicts and effect of these changes. [7] If all handover constraints are fulfilled it can initiate automatic sendover.

Sonification. Sonification stands out as a transformative support tool in air traffic control, converting complex data into non-speech audio. This allows ATCOs to interpret and interact with critical information through auditory cues. As defined by Hermann [12], sonification is "the use of non-speech audio to convey information or perceptualize data," enabling ATCOs to process intricate information and patterns intuitively and efficiently.

Auto-Coordination. The communication between Planning Controllers of adjacent sectors is automated to reduce workload. The requesting Planning Controller starts a coordination regarding a subject, e.g. like a flight level or a direct-to a certain waypoint, and sends it. The request is automatically checked for conflicts if it would be implemented. If so, the coordination is shown to the responsible controller to be responds with a rejection or an alternative value. If the request causes no issues, it is accepted by the controller working position (CWP) and all controllers are informed about.

Dynamic Heatmap. Dynamic HeatMaps is an on-demand tool with the primary objective of highlighting the development of congestion or hotspots within the ATCOs area of responsibility. The tool conducts predictions of the traffic to construct a comprehensive outlook of future air traffic, leveraging flight plan information and forecasted aircraft positions within a specified time horizon adjustable by the ATCO. It results in specific aircraft positions in the future. However, as the future is uncertain, the exact location is not very useful for assessing which area of the airspace is occupied. To overcome this limitation, we implement a transformation of predicted future locations into density plots, which is achieved by extrapolating predicted future locations of aircraft to capture a broader influence of aircraft in neighbouring regions. DHMs are visualized as colour-coded maps and employ a spectrum of high to low-intensity colours. The high-intensity colour indicates areas of heightened congestion or hotspots, providing ATCOs with an intuitive representation of potential areas that require attention. Conversely, low-intensity colours signify open spaces within the airspace. As an on-demand tool, DHMs offer ATCOs to activate when needed with flexibility in choosing a time horizon. The colour coding and horizon options are configurable, allowing it to be integrated with various radar displays. [7]

TraGAT. The main focus of Trajectory Generation and Advisory Tool lies on the generation of conflict free trajectories in dependence of a set of parameters describing the preferred trajectory type. These given specifications include sticking to a route network or generating short trajectories. For the automatic generation of a trajectory other flights and airspace restrictions can be considered when they are included in the trajectory request. As method for the trajectory generation Evolutionary Algorithms [13] in combination with Simulated Annealing are used.
The solution type is then defined by a set of weighted evaluation parameter describing criteria's like

- avoiding conflicts,
- prefer short trajectories,
- vertical structure and speeds of trajectory close to standard values,
- try to turn on official waypoints (beacons),
- similarity to original trajectory,
- usage of route network, punctuality and / or
- low number of speed changes.

Some of these evaluation functions do not work well together like preferring short trajectories in combination with using waypoints for turns. Those combinations should be avoided. The conflict avoidance is not only carried out for other flights but for restricted areas as well, as long as they are included in the trajectory request. Restricted areas have restriction levels like avoid at all costs, avoid, prefer to avoid. As a result, only one trajectory is given back at the moment. For a fast solution the optimization can be restricted to a one-point solution created by a Simulated Annealing algorithm. This is a typical solution created by controllers supported by CWP's like ICAS of DFS.

1.3 Validation Aim and Hypotheses

The aim of the presented validation was divided into two parts. On the one hand the feasibility of the SCO concept and system as validated should be assessed with the following hypotheses:

1. The controller's workload remains the same when using the support tools and a maximum of 80% of the declared capacity.
2. The SC's situational awareness is comparable to that of an ATCO in an ATCO team
3. The SC's trust in the system is comparable to that of an ATCO in an ATCO team

On the other hand, the aim was to assess most suitable support tools to enable the SCO concept. Therefore, this exploratory research proposed a set of different support tools to the participating ATCOs to gather their feedback regarding design, perception and usability.

Design as used in this paper describes the interface design including presentation of information and interaction with as well as the selection of addressed ATCO tasks and of presented information.

Perception in the sense of this paper refers to the appearance and feeling that ATCOs convey to or through the tools.

2 Method

2.1 Sample

The sample consists of a total of seven Air Traffic Controller Officers (ATCOs). All of the seven participants were male with an average age of 30.86 years and an average experience of 8.57 years.

2.2 Experimental Design

The validation campaign took place in the DLR Institute of Flight Guidance's Air Traffic Validation Center in Braunschweig in autumn 2023. The simulation tool NARSIM was used within the Air Traffic Management and Operations Simulator (ATMOS) enabling real-time human-in-the-loop simulations.

The validation campaign was conducted with a 2 x 2 within subject design with the factor's workload (high and low) and workplace (normal vs. single). Furthermore, the normal working condition is named baseline and the single controller position is describes as solution scenario. Baseline scenarios are reference scenarios with two air traffic controllers (Radar Controller and Planning Controller) working together on the sector without additional means. Six ATCOs conducted the validation in teams of two executing the baseline scenarios together and the solution scenarios sequentially. One ATCO was supported by an additional domain expert not involved as participant. Therefore, this ATCO conducted the baseline scenarios always as Radar Controller. The baseline high scenarios were conducted twice by the three ATCO pairs with switched roles (Radar and Planning Controller), whereas the baseline low scenario was conducted once per team with one allocation to roles. Scenarios are summarised in **Table 2**.

Table 2. Scenarios of the validation.

Scenario #	Scenario name	Number of ATCOs per run	Traffic amount
1	Baseline low	2	40% declared capacity (27 aircraft/hour)
2	Solution low	1	40% declared capacity (27 aircraft/hour)
3	Baseline high	2	80% declared capacity (55 aircraft/hour)
4	Solution high	1	80% declared capacity (55 aircraft/hour)

The scenarios were based on a real traffic sample that were adjusted based on expert judgement in terms of sequence and amount of aircraft. Air traffic controllers for participation were acquired throughout Europe leading to the situation that they were asked to perform the validation runs on a foreign sector they have no endorsement for. This was considered by reducing the traffic amount of high and low scenarios to 80% respectively 40%, simplifying vertical boundaries of adjacent sectors and conducting a sector briefing prior to the validation runs (see **Table 4**).

The validation focused on the upper airspace (here: Flight Level 245 and above) and the Celle sector from the airspace above north-west Germany was chosen. A Reduced Vertical Separation Minimum (RVSM) equipment coverage of 100% was assumed resulting in a standard vertical separation minimum of 1000ft (no aircraft above FL 410). Lateral minima of 5 NM between aircraft and 2,5 NM to sector boundaries were applied. Furthermore, the scenarios were restricted to non-military traffic and without the influence of wind and weather to ensure a standard situation. As operational frame conditions no releases and agreements to adjacent sectors were assumed.

The validation runs were supported by one or two pseudo pilots handling aircraft inputs and one pseudo air traffic controller for all adjacent sectors handling coordination tasks. Each scenario included a predefined set of events as listed in **Table 3**. Since the development of traffic in the simulated scenarios is impossible to predict due to participants handling of the traffic some events were linked to a time-frame (5 minutes) rather than to individual aircraft.

Table 3. Amount and trigger of scenario events

Event	Time or aircraft related	Number of events (low/high scenarios)
R/F failure or wrong readback (Baseline) / CPDLC failure (Solution)	time	3/3

Pilot requests (RFL)	time	2/2
Sick passenger on board	aircraft	1/1
Differing exit flight level	aircraft	15/20
Release request	aircraft	2/2
Request from downstream sector (differing entry flight level or direct)	aircraft	4/3
Request from upstream sector (differing exit flight level or direct (from upstream sector)	aircraft	3/3
Missing initial call	aircraft	1/1
Rate deviation	time	0/2
New aircraft	aircraft	0/1
(planned) Conflicts	aircraft	4/7

2.3 Set-Up

As CWP a radar display based on the ICAS CWP of the German air navigation service provider (DFS) with respect to user interface and functionality was used for all validation runs and working positions. However, for several parameters influencing the visual appearance of the CWP different settings were offered to the controller to allow a better personal experience and familiarity. For example, two colour-sets were offered which represents the two philosophies in presentation of radar display: negative presentation (bright head symbols and labels and dark background) and positive presentation (bright background and dark head symbols and labels). The baseline system included colour-coded flight status (incoming, in sector, leaving, passing by), adjustable velocity vector, optional trail dots, a flight-label resolution, a minimum distance measuring tool, a mouse-over trajectory indication and a conflict detection tool with a lead time of 7 minutes indicating separations of less than 10 NM. System inputs are done by mouse.

Any system inputs were conducted via mouse directly to the radar display. No (electronic) flight strip display was available (substituted by label functions) in any scenario. For the coordination process no telephone communication was possible, instead an electronic coordination interface within the radar display operated with mouse was provided for selected/required coordinations (exit/entry flight level, directs, release requests, request aircraft on frequency, new aircraft) for all scenarios.

2.4 Procedure

The validation per ATCO team last two and half days starting with a half day of introduction and training on the system. The following two days the validation runs and questionnaires were conducted. **Table 4** summarizes the validation process applied to all participants. The sequence within baseline scenario (high, low) and within solution scenarios during day 2 and 3 varied between participant pairs to exclude trainings effects within results. The Baseline high scenario was validated twice with inverted roles of the both ATCOs and changed callsigns of the simulated aircrafts (not necessarily the third Baseline run).

The duration of each validation run was one hour with 13 minutes for the ATCOs to set up radar display and get into the scenario and 47 minutes for actual validation run time.

Table 4. Validation procedure

Day	Validation process
1	• general briefing (project, validation aim, scenarios, pre-validation questionnaire) • sector briefing • introduction Baseline System • training Baseline System • introduction Single Controller Operation System • training Single Controller Operation System
2	• first Baseline run • first Solution run ATCO 1 • first Solution run ATCO 2 • second Baseline run
3	• second Solution run ATCO 1 • second Solution run ATCO 2 • third Baseline run • post-validation questionnaire

During the validation the participants answered questionnaires prior the validation runs, after each validation run and at the end including standardized questionnaires as NASA-TLX, SATI and SASHA as well as tailor-made questions.

2.5 Tools in the Solution Scenarios

The system demonstrator used for solution scenarios was based upon baseline system including support tools described in Chapter 1.2 and elements of the proposed Single Controller Operations concept. For solution scenarios, a CPDLC coverage of 100% for single basic instructions (level, heading, turn, direct, rate, speed, frequency) was assumed. The participants were asked to use CPDLC as far as possible in solution scenarios, but had the possibility to use radio communication via headset. CPDLC-instructions were conducted via mouse input directly on the radar display. An impression of the SCO system is shown in **Figure *1***.

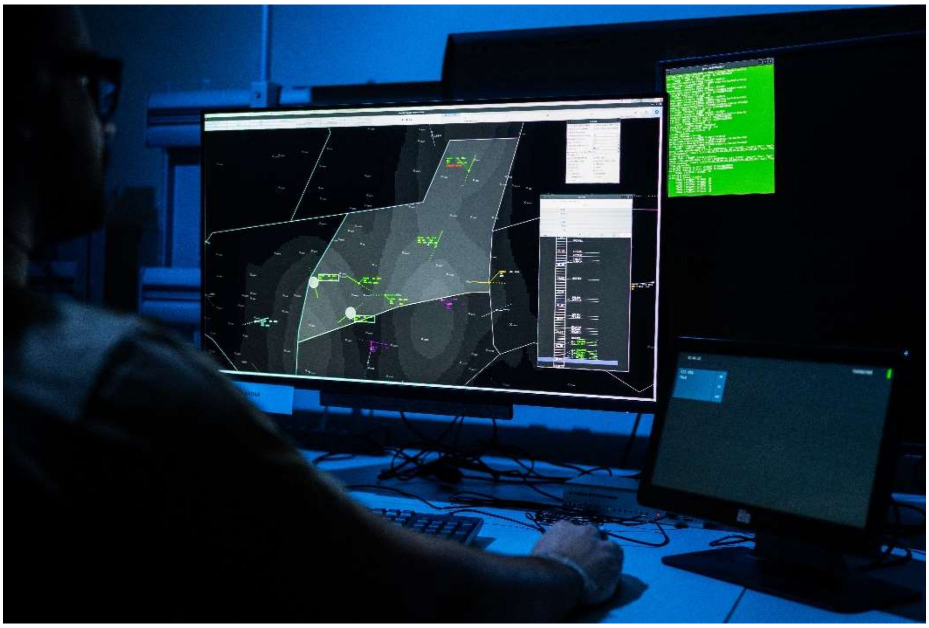

Figure 1 Impression of SCO system with visible AG, BATMAN and DHM

Attention Guidance. AG is used in the validation for detected conflicts, aircraft approaching sector, CPDLC-Failure and sick passenger. Precondition is always that AG is triggered for considered events externally, e.g. a conflict detection tool or an CPDLC-initial call.

BATMAN. The Boundary Arrival Task Manager is used in the validation as described in Chapter 1.2 and positioned on the right side of the radar display.

Sonification. Sonification's implementation in ATC is intended to be both practical and adaptive, addressing a range of scenarios in the present validation with distinct auditory cues:

1. CPDLC Login
2. BATMAN - Necessary Flight Level (FL) Change with Blocking Traffic
3. BATMAN - Necessary FL Change, Blocking Traffic Has Occurred
4. BATMAN - Necessary FL Change Without Blocking Traffic
5. Deviation from Assigned Rates
6. Notification of a Sick Passenger via CPDLC

Blocking traffic referring to a situation where one aircraft does not have a current conflict (infringement of minimal separation if ATCO does not intervene), but has to change the FL to comply with handover constraints with simultaneous crossing traffic between current FL and intended FL.

Auto-Coordination. This tool can be interpreted as an enhanced functionality of electronic coordination used in baseline scenarios. There was no direct interaction with BATMAN, but if new handover conditions are set BATMANadapted to it.

Dynamic Heatmap. Dynamic HeatMaps was used in the validation as described in Chapter 1.2 and positioned on the right side of the radar display.

TraGAT. For the described validation two different possibilities were provided to apply the trajectory generation to a flight but only one predefined solution type (stick as close as possible to the original trajectory) was offered.

2.6 Data Gathering and Analysis

For the data analysis, standard questionnaires were used in the validation. For the measurement of workload, the Nasa-TLX [14] was selected. It is a well-known and established multidimensional assessment tool that rates perceived workload in order to assess a task, system, or team's effectiveness or other aspects of performance. It uses as 6-item scale and results in a combined NASA-TLX score from 0 to 100 (0 = workload insignificant; 100 = unable to perform) [14]. For measuring situation awareness, the SASHA-s questionnaire was selected. The SASHA-s assesses the level of situational awareness during the previous working period(s). In its short version it also uses 6 items rated on a scale from 0 to 6 (0 = "Never"; 6 = "Always"). The resulting score also ranges between 0 and 6 with an average of 3 [15]. In addition to workload and situation awareness the solution scenario system provided additional assistant systems to the participant that also needed to be evaluated in terms of trust. Therefore, the SHAPE Automation Trust Index (SATI) was applied. The SATI also contains 6 items on a score from 0 to 6 (0 = No Trust in the System; 6 = Trust in the System). The resulting score is also a value between 0 and 6 [15]. NASA-TLX, SASHA, and SATI provide detailed procedure to calculate their result scores.

In addition to the standard questionnaires, tailored questionnaires consisting of statements that had to be rated on a 5-point or 7-point rating scale were used. The tailor-made items are described in the result section. With regard to the proposed support tools, the ATCOs were asked to comment on their usability, understandability, usefulness, trustworthiness, simplicity and influence on safety.

Furthermore, during the debriefing individual feedback and comments were collected. They were allocated to a topic (scenario, frame condition, system (part)), to concerned support tools or baseline and to a type (bugs, questions, relevant for analysis, suggestions for improvements, notes for improved validation procedure). All feedback allocationed toone support tool were grouped to identify same or equal comments.

3 Results

3.1 General Results Regarding SCO Concept

Participants were asked to assess their average experienced traffic during their last operating month. Results are shown in **Figure 2**. The validated scenarios can be allocated to the two bars indicating 21-30 and 41-50 aircraft per hour.

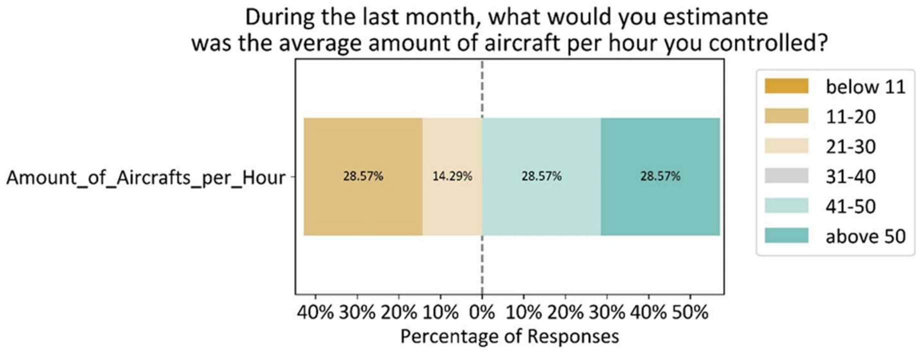

Figure 2 Subjective assessment of average traffic experienced during last (operating) month

Results shown in the following are focused on participants feedback regarding design and perception. The focus is divided into two parts: the overall SCO concept on the one hand and the individual support tools on the other hand. Furthermore, the gathered individual feedback during debriefings sometimes points towards single functionalities of one support tool.
As all described support tools and frame conditions were validated together, the overall assessment of ATCOs regarding workload (see **Figure 3**), system trust (see **Figure 4**) and situational awareness (see **Figure 5**) was crucial to determine system perception and feasibility of the overall SCO concept.

In both traffic conditions the participants rated their workload higher in the solution scenarios than in the baseline scenarios. However, the mean value deviation is small (5.54 and 6.81). Furthermore, as per concept and validation setup, in the solution scenarios the same traffic amount was worked by one ATCO instead of two in the baseline scenarios.

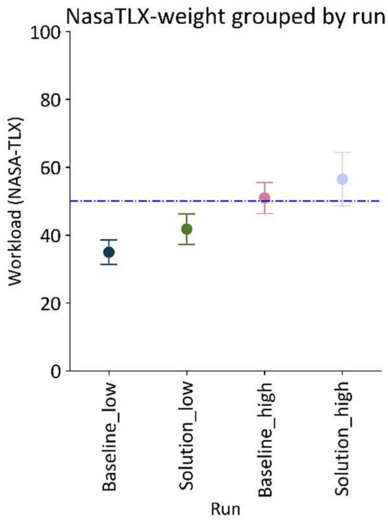

Figure 3. NASA-TLX per scenario

For automation trust (see **Figure 4**) and situational awareness (see **Figure 5**) the highest value is given for baseline low scenario (3.43 respectively 5.57) with a distinct distance to all other scenarios. This indicates a decrease in situational awareness and trust with increasing traffic, but also in comparison with SCO system. Again, it has to be considered that solution scenarios were conducted by one single ATCO. Besides, the difference between baseline high and solution high scenarios is marginal. Therefore, a positive impact of the system (resulting from support tools) can be concluded for these two parameters for high traffic amount.

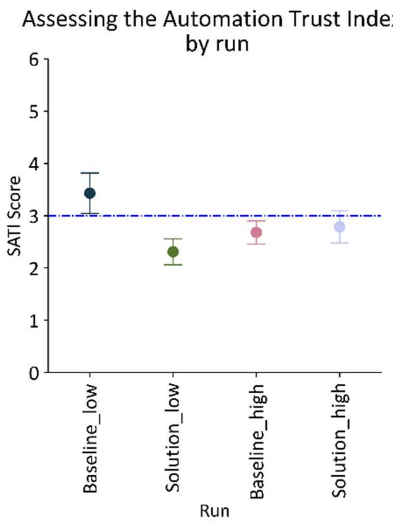

Figure 4 SATI per scenario

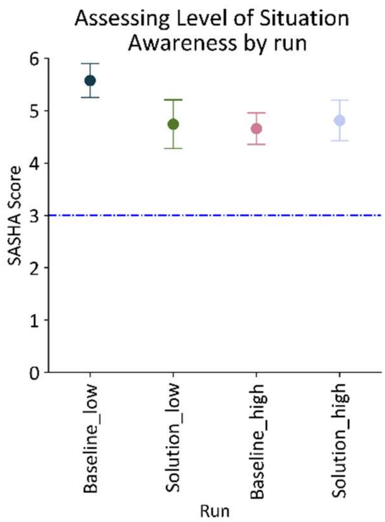

Figure 5 SASHA per scenario

Individual feedback confirmed "generally good support from the tools", especially for low traffic scenarios. But participants consider them not yet conceivable for SCO. All ATCOs mentioned CPDLC frame condition as main enabler for SCO although only basic instructions were possible. Another feedback expressed the solution system to be too extensive and some support tools should be rejected.

3.2 Tools

For a more detailed analysis a closer look to the assessment of the support tools is required. Therefore, six tailored questions were asked after each solution scenario run.

In the following subsections, only the results of validation runs with high traffic amount are depicted in figures, as the results do not deviate substantially between high and low scenario. The scale presented to the participants to rate the tools with respect to the question is shown in **Figure 6** to enhance readability of the following figures.

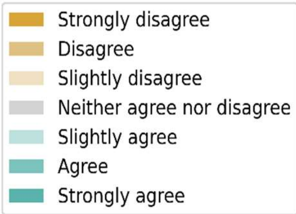

Figure 6 Rating scale

The results presented in figures 6 to 11 are summarised subjective answers of all participants to the tailored questions per support tool following the rating scale. In the following subsection they will be described first. Thereafter, if applicable, summaries from individual feedback are given followed by a short conclusion.

Attention Guidance. AG tools was used extensively by ATCOs (see **Figure 7**). Green bars on right side of the dotted line indicate positive perception with increasing agreement related to the respective question, orange bars on the left side negative perception. This applies to all of the following figures. User also express high levels of trust in the functionality as well as usefulness in the information provided by the system. Majoritarian, they deemed AG to work as expected, support them to work safely and provide the information in an easy to understand manner.

Individual feedback confirmed participants liked the visualization of information on the main radar screen and deemed it useful for highlighting events. They propose additional events to use AG for.

Overall, the AG tool was perceived useful in supporting ATCO tasks as it helped situation awareness and build trust in the tool.

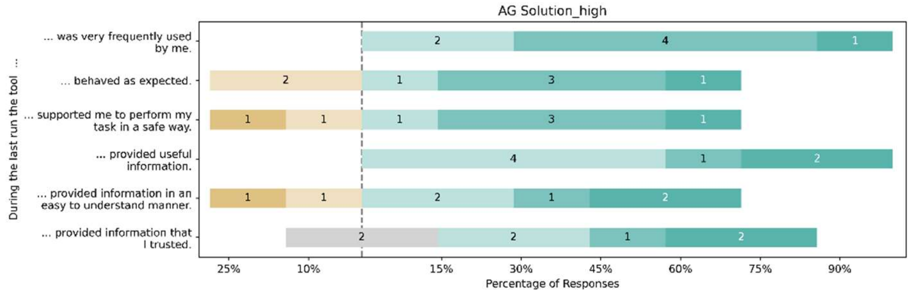

Figure 7 Results tailormade questions Attention Guidance

BATMAN. This tool was less used by the ATCOs in the runs, which can be traced back partly to missing trust, unexpected behaviour and/or difficult to understand presentation (see **Figure 8**). The latter might be a result of the presentation on an additional screen beside the radar screen, moved the tool out of the visual focus.

One core functionality of BATMAN is based on conflict detection, which did not always work properly (based on additional ATCO feedback) for the use to detect potential conflicts when applying changes to follow sendover conditions. This can serve as an explanation for less trust. Nevertheless, ATCO highlighted the two BATMAN functionalities to automatic sendover aircraft to next sector and to check for potential conflicts if intending to climb or descent an aircraft to its exit flight level positively. The first mentioned were assessed to be implemented well ("Auto-Sendover is good, takes a lot of work off your hands").

To conclude, main drawbacks of BATMAN are the presentation of information and that crucial detection of possible conflicts did not work properly. In addition, the summarising of different functionalities in one tool might be unnecessary or even obstructive.

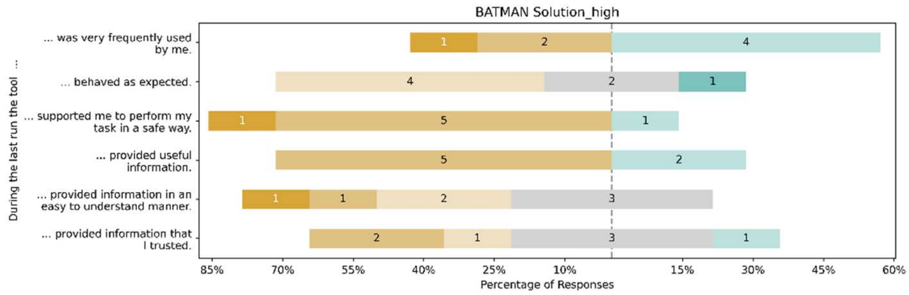

Figure 8 Results tailormade questions Boundary Arrival Task Manager

Sonification. The tool was assessed to behave as expected, but to be neither supportive, nor easy to understand (see **Figure 9**).

Based on ATCOs' individual feedback both aspects can be traced back to missing training and partly wrong selection of situations to use Sonification for, which in turn increased workload ("Sonification very disruptive and generates additional workload").

Furthermore, the additional ATCO feedback provided a nuanced understanding of the operational application of Sonification, highlighting the delicate balance between auditory information provision and cognitive load management.

Sonification is a non-visual support tool. Besides the use for alerts this is the first time an auditory support tools were used in an air traffic control validation. Therefore, it was implemented to a wide variety of situations (see Chapter 2.5). Only the selected situation CPDLC-Login in combination with AG was assessed to be supportive.

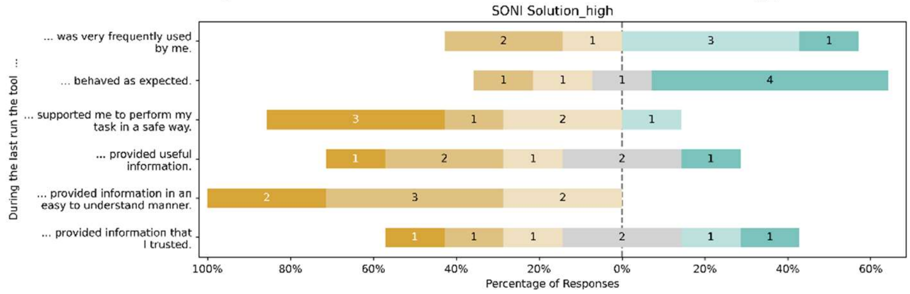

Figure 9 Results tailormade questions Sonification

Auto-Coordination. Auto-Coordination was widely used by participants and assessed to behave as expected. Feedback regarding, the way of presentation, trust and support to work safe was divers (see **Figure 10**).

According to individual feedback, the controllers had less workload, due to the automatic response of the system in non-conflict-requests. But, due to the quick response and the visualization only in a dialog window, the initiator of the coordination could miss the response.

The information provided by Auto-Coordination tool was difficult to grasp leading to additional workload although the functionality was assessed useful This can be identified as a design issue to be solved.

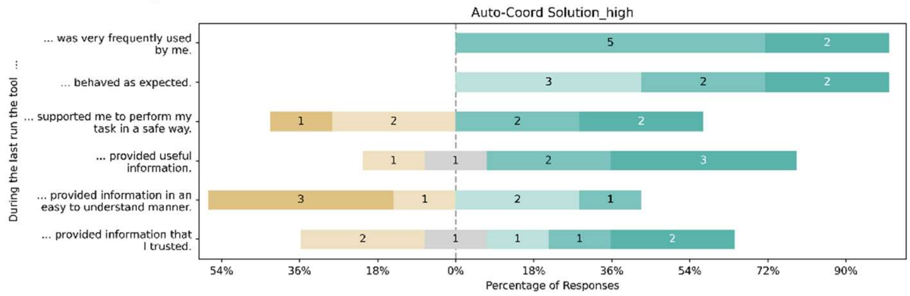

Figure 10 Results tailormade questions Auto-Coordination

Dynamic Heatmap. The participants feedback from the questionnaires for the DHM tool can be categorized into two parts. The first part represented the intended features and functioning of the tool. For this part, the user deemed the information provided by DHM as expected, which they can trust (**Figure 11**). Additionally, the information visualization is also considered easy to understand and intuitive. The second part of the feedback corresponds to the intended use in performing ATCO tasks. In this part, users could not correlate the information, resulting in the tool not being used frequently and information needed to be more supportive of ATCO tasks.

Individual feedback confirmed that the selection of presented information did not support participants, whereas they liked the presentation itself.

A direct use of the DHM by ATCOs based on sector occupation should be discarded for SCO.

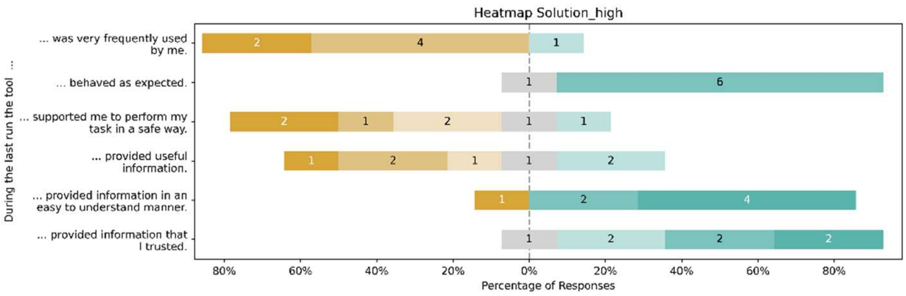

Figure 11 Results tailormade questions Dynamic Heatmap

TraGAT. Participants were not convinced that this tool would be helpful and did not use it (see **Figure 12**).

Individual feedback confirms that partly participants did not use the tool at all as it is "difficult to access". Feedback from participants using TraGAT shows that they lack an understanding of how the tool works ("does the system knows why I like to calculate a new trajectory?")

Based on the relatively high amount of neutral responses to all questions but the frequency of use, it can be assumed that partly it was not intuitive enough or not clear at all to the ATCOs how to activate or use the tool. Furthermore, the solution type "stick as close as possible to the original trajectory" was predefined for TraGAT. In turn, the controllers did not see an improvement when they applied this functionality tentatively to a conflict-free trajectory.

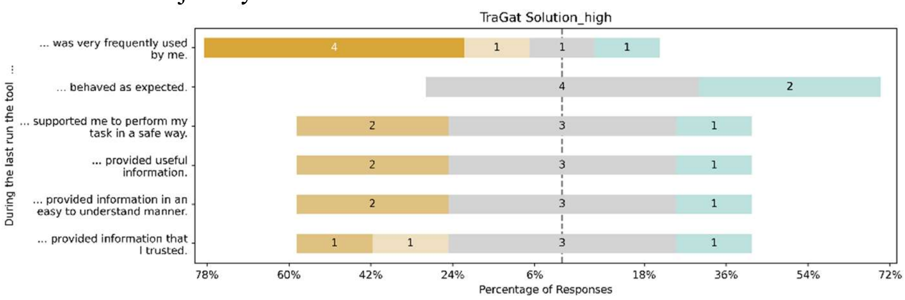

Figure 12. Results tailormade questions Trajectory Generation and Advisory Tool

4 Discussion

Main aim of the presented validation was a proof-of-concept and an identification of most-promising support tools and functions to enable SCO. The results are sufficient to use for improvements and refinement of the concept and the system. Especially the diverse use of tools showed which design concepts support ATCOs in an SCO environment. One major result of this validation is that workload is increased due to an oversize of support tools. Debriefing feedback partly referred to single functionalities of tools. Therefore, rejection of some support tools (e.g. Heatmap) and focus of smaller functionalities (e.g. auto-sendover from BATMAN) should be considered for future research in support tools for SCO.

Most promising support tools is Attention Guidance which showed required support for an SC to quickly identify important tasks and to be guided to essential information. Improvements should be strived for Auto-Coordination, Sonification and TraGAT.

The design of the presentation for Auto-Coordination was too difficult to grasp. As coordination will stay an important task for SC this led to higher workload.

In retrospect, the decision to offer only the solution type "stick as close as possible to the original trajectory" for TraGAT was not the best selection for the introduction of such a tool. An automatic solution proposal should be show upon conflict detection.

The cognitive capacity of ATCOs, especially in high-stress, high-stakes environments, is a premium resource. Sonification cues that are overly protracted or complex not only risk cognitive overload but also dilute the urgency and clarity of the information conveyed. The operational environment of ATC is a mosaic of auditory and visual stimuli. In such a context, the clarity and distinctiveness of Sonification cues are paramount to ensure that they cut through the ambient noise and deliver clear, unambiguous signals. The Sonification system must be finely attuned to the operational tempo and context of ATC. Sounds that induce undue stress or alarm can be counterproductive, distorting the situational awareness that Sonification seeks to enhance. The synergy between auditory and visual information streams is a cornerstone of effective ATC operations. Sonification cues must complement, not compete with, visual cues, ensuring a harmonious sensory interplay. Participants highlighted the positive effect of the concurrence of Attention Guidance and Sonification.

The questionnaires used for assessment are capable to measure subjective perception, what was intended to gather ATCOs feedback which tools fits best for enabling SCO. The comparison between tools allows conclusions about which design approaches works best for SCO support tools, even if the presented information is assessed as not required or not trustworthy. The overarching standard questionnaires ensure reproduction of the influence of the complete proposed SCO system on core parameters for ATC (workload, situational awareness and trust), which needs to be within acceptable range to judge the concept and system feasible.

The influence of trainings effects was minimized as far as possible by introducing baseline and solution system to the participants at the first day and change of sequence of low and high runs between participants.

As the main interface system is based on one operational system of the German ANSP DFS, the sector used for validation from EUROCONTROL and ATCOs participated from Austria and Germany (different operational system, no endorsement for the validated sector) the results can be seen as transferable to other ANSPs (sectors, ATCOs, systems). The validation took place in an en-route sector of upper airspace (here: FL

>245). Accordingly, the results cannot necessarily be transferred to other air traffic control sectors.

5 Conclusion and Next Steps

The present validation results show that the SCO concept is basically usable and that situational awareness and system trust of ATCOs in SCO is comparable to that of ATCOs in teams of Radar and Planning Controller with same traffic load (80 percent declared capacity). However, the workload is assessed to increase slightly. This can be traced back to the concrete support tools and their design as used in the validation.

The tailored questionnaires showed feasibility to identify diverse causes for non-acceptance or non-usability of ATCO support tools for the use in an SCO environment. From the questionnaires and the debriefing feedback it can be concluded that to be supportive a support tool for SCO requires:

1. an easy access design,
2. an understandable behaviour,
3. a suitable selection of supported task/situation,
4. a suitable selection of information presented,
5. a suitable design of the presentation of the information,
6. a proof of its functionality in operation

Except the last point these are all design related parameters. If one of the above conditions is not met the support tool is used less and trusted less. For example, TraGAT lacks an easy access design and Heatmap a suitable selection of supported task. In the overall view the design for SCO support tools should at best be such that information are presented directly on main radar display with as less text as possible. Furthermore, design of the presentation of the information which leads to a highlighting of new information were assessed as the most supportive and were even requested for support tools which did not had a comparable feature.

Future validation (and possible operational implementation) should put more emphasis on training of the new system. In general, the number of new support tools and functionalities made available to ATCOs must be reduced. As there is no use case for Heatmap it should be rejected for a future validation for direct use by the ATCO. The design of BATMAN would have to be revisited and a selection of the most supportive functionalities should be conducted. For Auto-Coordination a requirement was identified to better visualise and include it on main radar display the presented information. The Attention Guidance tool was assessed as best support tool for SCO. There are possibilities for improvements via connection with an eye tracking system or extension to more situations. The scientific development and integration of support tools for SCO within ATC systems are profoundly intricate endeavours. The feedback from ATCOs underscores the necessity for a user-centric design philosophy. For Sonification this philosophy advocates for sound cues that are clear, concise, contextually relevant, and cognitively considerate. Future research should pivot towards the development of personalized soundscapes, exploring the potential of spatial audio to enrich situational awareness without contributing to sensory overload. Main drawback of TraGAT was the access and restricted usability. Meanwhile, a set of solution types is offered which can be easily tested by controllers to familiarize with the tool. Furthermore, an automatic solution possibility presentation is in development.

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References

1. EUROCONTROL Homepage, PRR 2022 Performance Review Reporthttps://www.eurocontrol.int/sites/default/files/2023-06/eurocontrol-prr-2022.pdf, last accessed 2024/01/20
2. EUROCONTROL Homepage, ATM Cost-Effectiveness (ACE) 2019 Benchmarking Report with Special Focus on COVID-19 Impacts in 2020, eurocontrol-ace-2019-benchmarking-report-special-focus-covid-19-impact-2020.pdf, last accessed 2024/01/20
3. EUROCONTROL, Network Manager: Annual Report 2021, p. 6, 2022, https: //www.eurocontrol.int/publication/network-manager-annual-report-2021
4. DFS Deutsche Flugsicherung GmbH, Luftverkehr in Deutschland. Mobilitaetsbericht 2022, p. 17, 2023, https: ¨ //www.dfs.de/homepage/de/medien/publikationen/
5. Fihel, A., Okolski, M.: Demographic change and challenge. In: Social and economic development in central and Eastern Europe. pp. 101-132, (2019)
6. Gerdes, I., Jameel, M., Hunger, R., Christoffels, L. and Gürlük, H.: The automation evolves: Concept for a highly automated controller working position. In: 33nd Congress of the International Council of the Aeronautical Sciences (ICAS), Stockholm (2022)
7. Jameel, M., Tyburzy, L., Gerdes, I., Pick, A., Hunger, R. and Christoffels, L.: Enabling Digital Air Traffic Controller Assistant through Human-Autonomy Teaming Design. In: IEEE/AIAA 42nd Digital Avionics Systems Conference (DASC), pp. 1-9, Barcelona, Spain (2023), doi: 10.1109/DASC58513.2023.10311220
8. Duong, V., Gawinowski, G., Nicolaon, J., Smith, D.: Sector-less Air Traffic Management. In: Proceedings of the 4 USA/Europe Air Traffic Management R & D Seminar (2001)

9. Volf, P.:Comparison of the Flight Centric and Conventional Air Traffic Control. In: 2019 Integrated Communications, Navigation and Surveillance Conference (ICNS), pp. 1-10. Herndon, VA, USA, (2019), doi: 10.1109/ICNSURV.2019.8735109.
10. Finck, T., Kluenker, C.S. and Martins, A.: Validation of the Flight Centric ATC Concept using Hungarian Airspace as an Example. In: AIAA AVIATION 2023 Forum. (2023)
11. Abdellaoui, R., Finke, M., Pick, A., and Ahrenhold, N.: Supporting Air Traffic Controllers in handling sector specific tasks, enabled by the use of the Boundary Arrival Task Manager. In: 42nd IEEE/AIAA Digital Avionics Systems Conference, DASC, Barcelona (2023), ISBN 979-835033357-2. ISSN 2155-7195
12. Hermann, T., Hunt, A. and Neuhoff, J. G.: The Sonification Handbook. Logos Verlag, Berlin (2011)
13. Gerdes, I., Klawonn, F. and Kruse, R.: Evolutionäre Algorithmen. Wiesbaden: Vieweg (2004)
14. Hart, S. G., Staveland, L. E.: Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. Human mental workload, 1, pp. 139-183 (1988)
15. Skybrary Homepage, EUROCONTROL, FAA.: (2015). A Human Performance Standard of Excellence. www.skybrary.aero
16. DIAL (Individual and Automated Air Transport) Homepage, http://dial.dlr.de, last accessed 2024/01/23