The Use of Conflict Detection Tools in Air Traffic Management – an Unobtrusive Eye Tracking Field Experiment During Controller Competence Assurance

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ABSTRACT

This study aims at explaining loss of separation events over the Swedish air space in 2011-2012, which occurred despite an automated conflict detection tool working as designed. The study suggests that there may be a trade-off between spending visual scan time on own conflict detection versus visual scan time spent on examining potential conflicts presented by the conflict detection automation. The issue is hard to solve, and is unfortunately far from resolved. This area of research requires a substantial applied research effort, if the goal is to both increase safety and capacity of ATM through the use of automation.

Keywords

Eye tracking, situation awareness, air traffic control, air traffic management, visual attention, automation

INTRODUCTION

2011 – 2012 a number of incidents were recorded in the air space over Sweden. Two typical situations were found. First, the Air traffic Controller (ATCO) did not detect the situation until a separation minimum was infringed and hence the aircrafts simply came to close to each other. The other situation was when the ATCO detected the situation late (too late) and he/she then needed to act rapidly (stop climb/descend or issues significant heading change).

An analysis of the events conducted by the LFV showed that available visual decision support systems either did not give a sufficiently clear indication of imminent conflicts, or that the ATCO did not pay attention to the systems.

BACKGROUND TO THE STUDY

An awareness campaign was launched shortly after the incidents at LFV units to draw attention to the subject. Briefings were held and discussions mediated at the air traffic control centers. A set of posters (Figure 1) describing the situations with separation infringement or late detection were designed by the occurrence investigations team and distributed to the operational units.

The consolidated result from the occurrence investigations did not point to a common denominator. However it was noted that the set up of the working position varied among the ATCOs, the actual usage of the tools available varied from not using them at all to using them as a means of working the traffic.

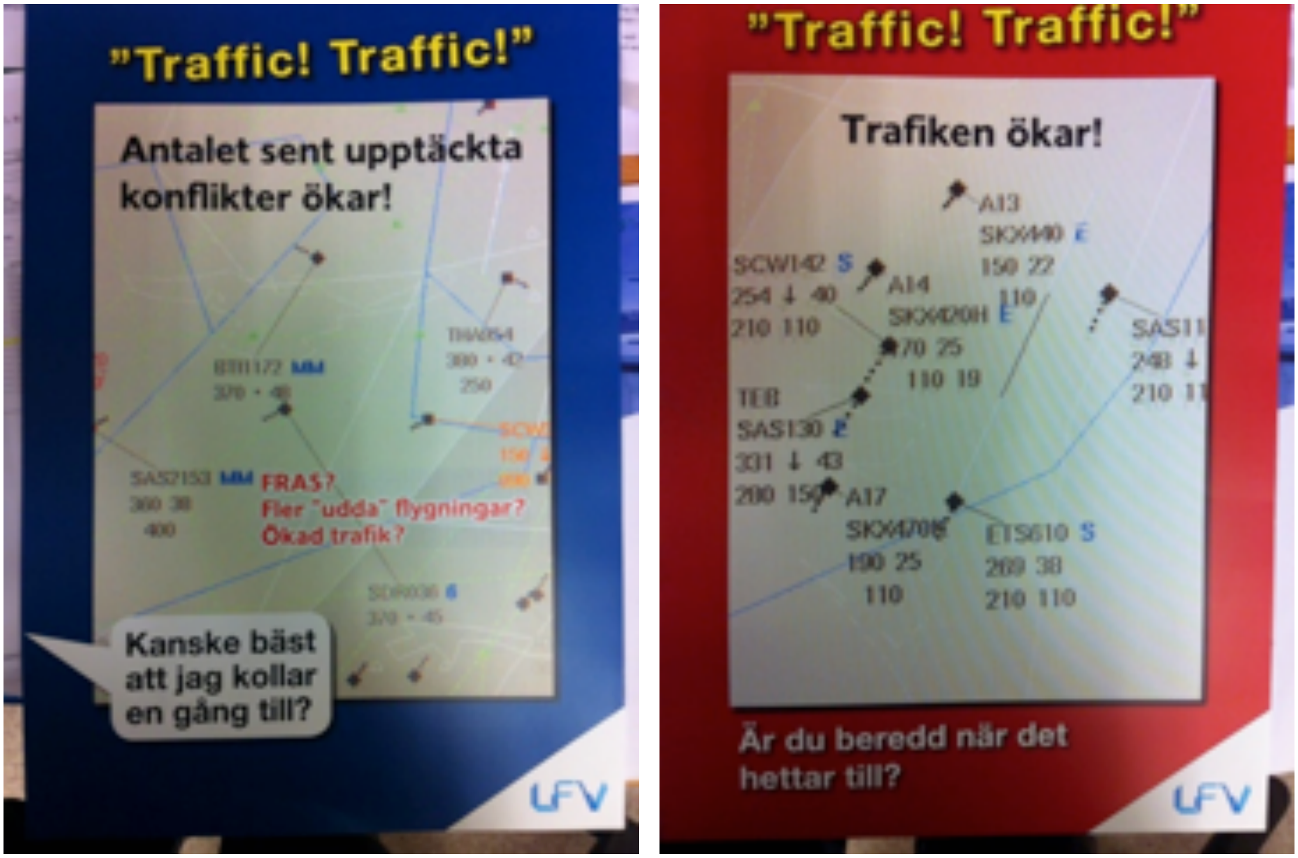

Figure 1. Example of posters used at the operational sites, each also showing a close up information on the radar tool. Translation from Swedish, poster to the left, top "There is an increase in late conflict detection." Talk bubble, bottom: "Perhaps I should check one more time?". Right, top: "Increased traffic". Bottom right: "Are you prepared when it heats up?".

The discussions and briefings following the distribution of the above mentioned posters were well received among the ATCOs and a recommended set up of the working positions was agreed upon. It was also understood that the use of a few posters pointing out hazards, inappropriate thinking/acting followed by discussions and briefings cannot solve the underlying problem.

In parallel to the above mentioned events, the emerging performance requirements within safety and cost efficiency was communicated for the so called reference period 1 (ref EU-regulation 691/2011), an evaluation period before setting more strict targets for the period from 2014 and beyond. For safety, it means that the effectiveness of the safety management system (SMS) is assessed as well as the use of a severity and risk classification tool (RAT). Finally the prerequisites for safety reporting are assessed, namely the presence of just culture in practice. The measures within safety performance tell something about what can we learn and what kind of processes we have to identify and change things to the better. For cost efficiency the target is to decrease LFVs cost with 3,5 % in general.

The expectations from European Commission on Air Navigation Service Providers (ANSPs) are considered to be demanding in particular when the deregulation and increasing competition pave the way for so called low fare ANSPs. A typical low fare ANSPs adhere to minimum requirements in general and do not take on research, development and support to validation etc. A low fare ANSP may keep safety sharing activities to a minimum, which means that they only share what is regulated.

It became clear to LFV management that efficiency and safety required both direct action and a proactive strategic approach. The Director General of LFV took personal responsibility to initiate collaboration with Linköping University, resulting in the project "amplify TEAMWORK with automation". The project addressed both safety management and the ATCO working position. The safety management part (not reported here) focused on the process within the SMS of identifying and implementing improvements based on safety reporting. The problem addressed here is how the ATCOs used (or did not use) the different kinds information presented on the various displays to manage the traffic safely and orderly, in a normal ATC working position (Figure 2).

VISUAL ATTENTION TO MAINTAIN "THE PICTURE"

For an ATC to maintain "the picture" of their traffic situation, they need to continuously scan the traffic situation. In the current study, the traffic situation is represented through various tools, such as radar, conflict detection, and sector aircraft list. The tools are interactive visualizations that do more than just display data. Thus, some fixations will have to do with "interfacing" (to enter data, to adjust the view), rather than to pick up information about the traffic situation. Alternatively, traffic can be visualized as a 3D rendering [2]. This has similarities to presenting traffic as an outside view of a remote location using video cameras, such as in virtual air traffic control (ATC) towers. Other issues also emerge when rendering an outside view. For instance, on virtual outside views, a too low display frame rate will generate an illusion of aircraft moving faster than they actually do, which is important to consider when monitoring landings [4]. Further, if the resolution of the display is too low (measured in lines or pixels per visual angle) it will be hard to detect and identify objects [16].

In this project, tool usage is operationalized as inclusion in controller visual scan patterns, through visual fixations on tools. Even though this does not guarantee that information is actually taken in, it is an important prerequisite. Previous research in cockpit instrument failures has shown that sometimes inclusion in scan patterns is associated with detection of events, but in other situations it does not help to attend to a relevant display [8]. Thus, the design of the display and training in comprehending it is clearly also important. However, previous research has shown that on the whole the mind is indeed where the eye is – what is attended is also what people are aware of [11]. During dynamic scenarios, previous research has indicated that the number of fixations is an important performance measure [5, 11], especially for detecting important cues. It is so strong that experts may even fixate more than novices during detection [3]. In contrast, to orient during less dynamic periods, dwell time is a stronger indicator [5], and experts may require fewer fixations than novices to get a picture of the situation [3].

The scan patterns are central to the controller maintaining “the picture” of the traffic situation, their “situation awareness” (SA). The controller has several “schemas” of situations that are triggered by cues in the environment that guide visual search of displays. A study using an ATC-inspired game showed that the design of cues could have a large influence on the schemas that are (and can be) used. In that study, in one condition the participants had to monitor a list of flights to detect what to do, and in the other condition, color-coding on a radar-like display were additional cues, as a complement to the lists. The color-coding was shown to have a large effect on visual attention and on game performance [1]. In another study, that only used a radar display, subjects were given 90 seconds to understand a situation and detect conflicts. A higher number of aircraft resulted in longer detection times, whereas color-coding of altitude (restricted to four altitudes and four colors in the experiment) reduced detection times. No changes in altitude occurred in that experiment [15]. Another study showed that it was possible to differentiate between three tasks in an ATC-like simulator based on eye tracker data, when it was known that the controller performed a task belonging to that group of three tasks [6].

Neisser [12] describes perception as a schema (expectations, current understandings) guiding visual search, sampling the environment, adjusting the schema, that in turn samples the environment, continuing the perceptual cycle. As described by Klein, Crandall and Woods [7] this is a process of sensemaking where current frames (understandings) of data are challenged (and possible the situation is re-framed). The amount of information needed to keep track of a situation, to fill the frame, is an aspect of cognitive load. It can be divided into three facets. a) Intrinsic load (due to the information required), b) extraneous load (due to ineffective ways of presenting the information) and c) germane load (beneficial for schema construction). Although germane load may be beneficial for novices, it may hinder experts [13].

However, and as we also measure in this study, there is a limit to the number of visual fixations that a human can on average be expected to make per time unit, given a particular visual environment. This creates a dilemma. The controller scan patterns must both include cues for challenging the current understanding, and information needed for making decisions based on the situation as it is currently understood. To capture the unexpected, either scan patterns may actively search for it, or cues in the environment can be salient enough to capture (divert) attention as required. SA can thus be seen as an invariant, of the fit between schemas and the environment [19]. Fixation times do not only depend on the visual environment per se. A study of a conflict reduction tool showed that reducing the number of conflicts that the ATC had to handle also reduced fixation times. That tool reduced conflicts by making minor adjustment to aircraft speed before the aircraft entered the controller’s area (the area that aircraft were present in during speed adjustment was excluded from that experiment) [14].

Situation awareness depends **firstly)** on having relevant schemas for what may occur in particular environments, and **secondly)** on conducting active exploration using those schemas, and **thirdly)** on having at any point within activities filled those schemas with relevant current aspects for decision making of the situation, and **fourth)** on challenging the present understanding of the situation through exploring cues of associated with other schemas (understandings) to activate them.

TEAMWORK AUTOMATION

Automation is often described in terms of delegation of work [18]. However, coordination of work is equally important, since many activities are not completely divided between man and machine, but require teamwork.

Automation can be used for redundancy, as a team member. For instance it can provide redundant monitoring of the air space for separation conflicts. This provides an apparent benefit – if the operator misses a conflict, the automation might still find it. It however also has a downside – the information must be presented, and each item presented visually must also be scanned visually. This adds to the information that needs to be covered in controller scan patterns. The amount of added visual work **firstly** depends on how often the detection system must be checked, and on how many items in the detection system must be checked. The amount **secondly** depends on how many items elsewhere must be checked visually to confirm and understand what do be done about the information provided by the tools.

Automation could also be used as the main monitoring mechanism that the ATC would use as the starting point for visual exploration of the air space. It would have an apparent benefit – a more focused scan. But it would also have downside – reduced redundancy due to the controller not actively checking for conflicts. To take over control in case of automation failure, the controller nevertheless may need to scan relevant information. Adding automation to a controller task can cause changes in visual attention [17]. In a study [5] of a simplified task of taking control from an automated system, relevant visual attention was shown to be a benefit for taking control.

In this study, the controllers used the conflict detection tool (automation) as a redundant system for conflict detection.

RESEARCH QUESTIONS

Q1: How is visual attention distributed over ATM tools during regular work and during unusual events?

Q2: Is there a difference between visual attention in the planner versus the executive positions?

Q3: Is there a difference between visual attention in overflight versus climb/descend control areas?

Q4: Using this particular set of visual tools, how many fixations per second can on average be expected from a controller?

FIELD EXPERIMENT

To achieve as realistic recordings as possible, to maximize ecological validity, the experiment was run during competence assurance for the controllers. The actual runs thus both had the purpose of training and validation of the controllers, and to answer our experiment questions. The recorded position was identical to a real controller position (compare Figures 2 and 3), using the COOPANS platform (used in Sweden since 2005).

Figure 2. Normal ATC Controller position

Each position consisted of one ATC Planner (PLC) and one ATC Executive (Figure 4). (EXE). The PLC mainly work with coordination related to conditions outside the actual sector, as the area of responsibility. The overall aim of the PLC tasks is to ensure no surprises to the EXC and that the traffic enters the sector in a well organized way as well as meeting other sectors expectations on how the traffic should be handed over. The PLC does not talk to the aircraft, only to adjacent sectors and to other relevant interfaces. The EXE communicate with the aircrafts and issue the instructions needed to create a safe and orderly flow. In some cases the EXC and PLC uses the same tools to support decision making and planning and in some cases the usage of tools varies. The EXC and PLC sit next to each other. The EXC, PLC and the available automation are in this context considered to be a team, hence the overall performance are dependent on these components.

During each 2 x 45-miute competence assurance run, 4 planner/executive pairs worked together in parallel. ”Pilot” staff played out all verbal interactions with ATC. One planner/executive pair of each run participated in the experiment. They switched positions during the break between the two 45 minute sessions. To collect data unobtrusively, a stand-alone eye tracker was used

Participants

12 experienced (9-38 years) air traffic controllers (6 male, 6 female) participated in the experiments (Table 1). Two volunteer controllers were selected from each competence assurance group, balancing male and female participation.

P	M/F	Age	Exp	Sector	Role	Time
1.1	F	50	23	Over	Exe	2440
1.2	F	47	20	Over	Exe	2277
1.3	F	45	22	C/D	Exe	2687
1.4	M	37	9	C/D	Exe	2854
2.1	F	50	17	C/D	Plc	2393
2.2	M	42	17	C/D	Plc	1977
2.3	M	38	13	Over	Plc	2441
2.4	M	54	33	Over	Plc	1349
3.1	F	32	9	Over	Plc	2081
3.2	F	50	17	Over	Exe	1364
3.3	M	59	38	C/D	Plc	2356
3.4	M	55	34	C/D	Exe	2035

Table 1. Male / Female, Age, Experience, Overflight or climb/descend sector, executive or planner position, duration of recording in seconds.

Procedure

Verbal communications were recorded between the planner and executive taking part of the experiment using a microphone placed between the controllers. Radio communications were recorded using audio output from the simulator system. During each run, gaze was recorded for one of the positions. A Tobii X300 Eyetracker was placed in front of the two main ATC screens, sending data to the tracker computer. The VGA output from the simulator computers to the ATC screens were split, with one signal pair passing through to the ATC screens. The screens were captured using two frame grabber cards, converting the diverted VGA signal pair to USB. The frame grabbers were connected to a computer displaying them as a ”virtual video camera”. This avoids problems of shaky cameras, parallax errors from the video camera, and image resolution problems. This ”virtual video camera” was used as external video input to the eye tracker software (through a third frame grabber). The software then displayed the gaze plot on top of the video. This induced a delay between gaze capture and rendering of background video of about one second, which is of no consequence for the analyses conducted for this paper. A video camera was also positioned to simultaneously capture both the gaze plot from the frame grabber computer and the ATC operator position (See Figure 5). This allows a precise measure of the delay at every point of the recording (not required for this study, but required for planned episode analyses).

Figure 3. Experiment working position with five-point paper calibration grid (removed after calibration).

Figure 4. Executive and controller position pairs (eye tracking position to the right).

Figure 5. Each scenario was video recorded, showing both planner and executive, as well as the recorded ATC screens and the gaze plot recording (small screen next to the video camera in front in the photo) simultaneously.

Experiment design

We conducted a between subjects field experiment with two variables. We recorded the executive position in half of the runs, and the planner position in the other half. The runs were divided into two scenarios: overflight sector and climb / descend sector. (See Table 1, Figure 7). Each session started with a five-point calibration for each subject, followed by a short break before the actual experiment. Each experiment run contained normal ATC work, but also unusual events (aircraft failures and technical ATC system failures). Each scenario developed somewhat differently depending on ATC decisions, which is characteristic for ATC work. Thus, it was neither possible nor desirable to have the exact "same" conflicts in all scenarios. Pre-programmed traffic load was identical in each kind of scenario (overflight, landing/takeoff). For this analysis, recordings were cut at event onset if a main radar failure event was included in the scenario; some recordings are therefore shorter than others (see Table 1).

ANALYSIS

For the current analysis, each gaze recording was divided into areas of interest. We marked the location of the following tools and areas:

1. Main ATC Screen
2. Side Screen
3. Own control zone (light grey)
4. Other control zone (dark grey)
5. Conflict detection tool (only used in overflight scenarios)
6. Departures tool (only used in start-landing scenarios)
7. Lists of flights in the zone
8. Eye tracker (included to measure distraction from gaze on the tracker).

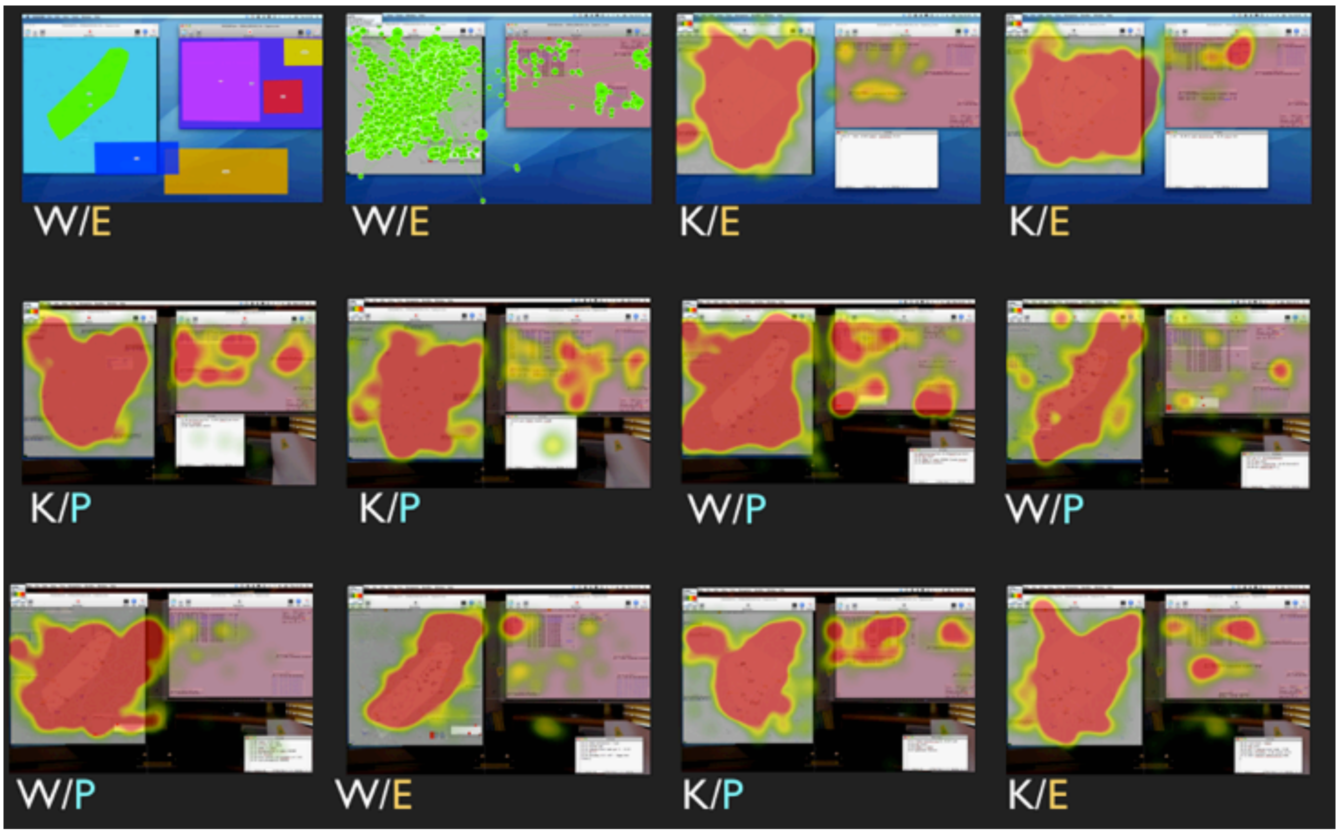

Figure 6. Areas of interest, heat maps W(overflight) K (climb/descend). P is PLC and E is EXC.

Figure 6, top left, illustrates the division of the screen into areas of interest. To the right, a gaze plot illustrates all the fixations from one trial. A heat map (remaining images) gives a clearer image of the hot areas of attention, red means an area with many fixations, yellow and green means less attention was spent on the area. The remaining area had few or no fixations.

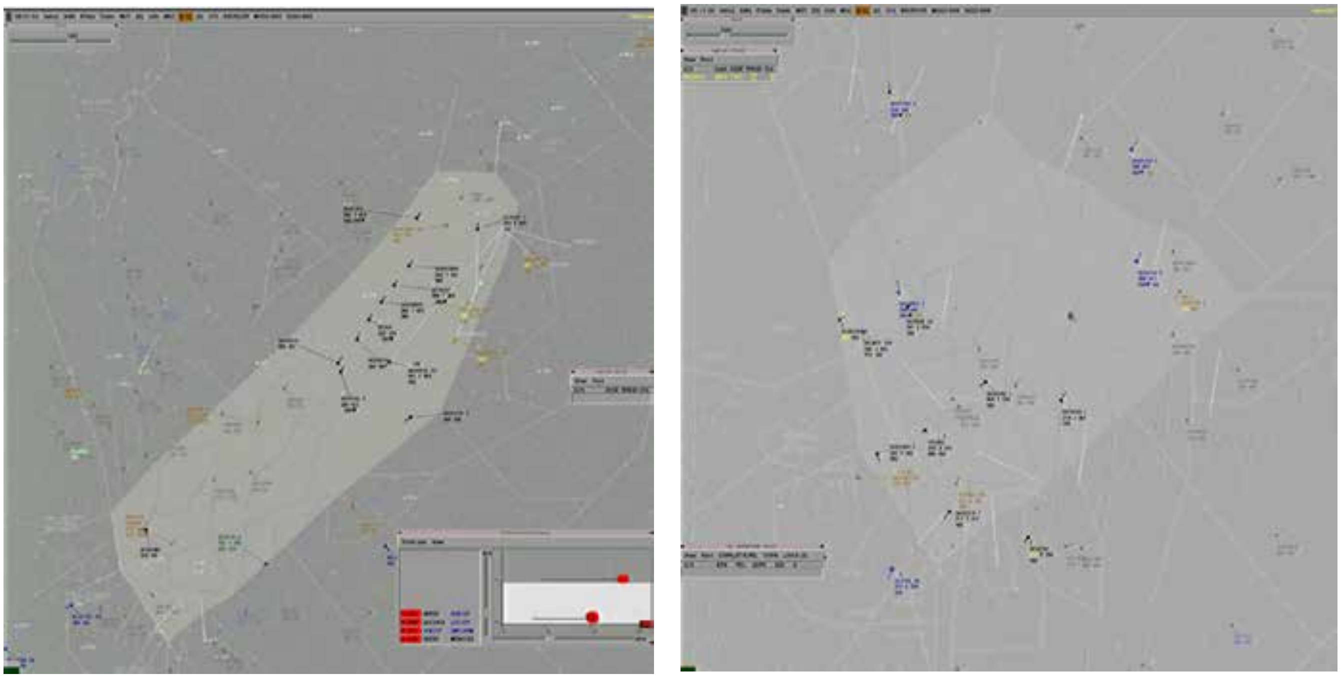

Figure 7. W (overflight) and K (climb/descend areas)

We analyzed the following metrics for each experiment participant 1) Total time in each area. 2) Time for the fixations only on each area 3) Number of fixations on each area.

Comparisons were made firstly using the four group experimental matrix (W/E, W/P, K/P, K/E). (4*3). Comparisons were then made by grouping based on each variable (sector type, role) 2*6, 2*6, using a two-tailed t-test for significance. For all comparisons, the results were first changed into percentages.

RESULTS

Looking at Figure 8, an obvious conclusion is that regardless of sector type or role, the controllers use the main 2K screen most of the time.

There is a small but statistically significant ($p<0.01$) difference between planner (solid) and executive (striped) usage of the 2K screen. The difference is, as expected, mirrored in the use of the other screen.

Going into more detail, analyzing tool usage divided over the screens (Figure 9) to answers questions Q1-Q3, it is equally obvious that regardless of role or sector type, usages are similar. The bar chart shows a slight tendency for the executives to pay more attention to their own zone, and the slightest inclination of planners to use the sector list more This slight tendency is emphasized (significant at $p>0.05$) when splitting the 12 participants into groups of six planners and six executives (Figure 10). This split mixes W and P areas. As a contrast, we have also split the 12 controllers into two groups of W and P areas in the same figure. This split instead mixes planners and controllers. Note that (Figure 9) the conflict tool was only used in the W (overflight) areas (red) whereas the departures list was only used in the K (climb / descend) areas (blue). Regardless of significance calculations, differences appear to be minor.

The conflict detection tool was used on average 1.28% (min 0.22%, max 3.50%) of the time in the W scenarios, and accounts for 1.79% (min 0.27%, max 3.58%) of the fixations. Note that in three of the six runs with conflict tool usage, there was a reduced alert mode event, for about 7 minutes (24%, 31% and 35% of the total analyzed time).

Fixations can be included in a scan pattern to resolve conflicts, so that several fixations may correspond to one usage situation. This result should therefore be examined further through analyses of episodes of tool usage (see Figure 11).

Regarding Q4, we found that on average, controllers managed 3.12 fixations per second (from 2.50 fixations to 3.86). This is reflected also in Figure 10, showing 17 fixations over 5 seconds (3.4 fixations / second). Including time of not attending to the displays, time goes down to1.99 fixations per second (from 1.1 fixations to 2.5). The amount of fixations per second needs to be examined further for different kinds of scan patterns and traffic situations, and with respect to what kinds of fixations take the most or least time.

Finally, the fixations on the eye tracker (distraction) ranged between 0.24% of the total fixations, to 0.81%, on average 0.24%. Distraction was thus quite low.

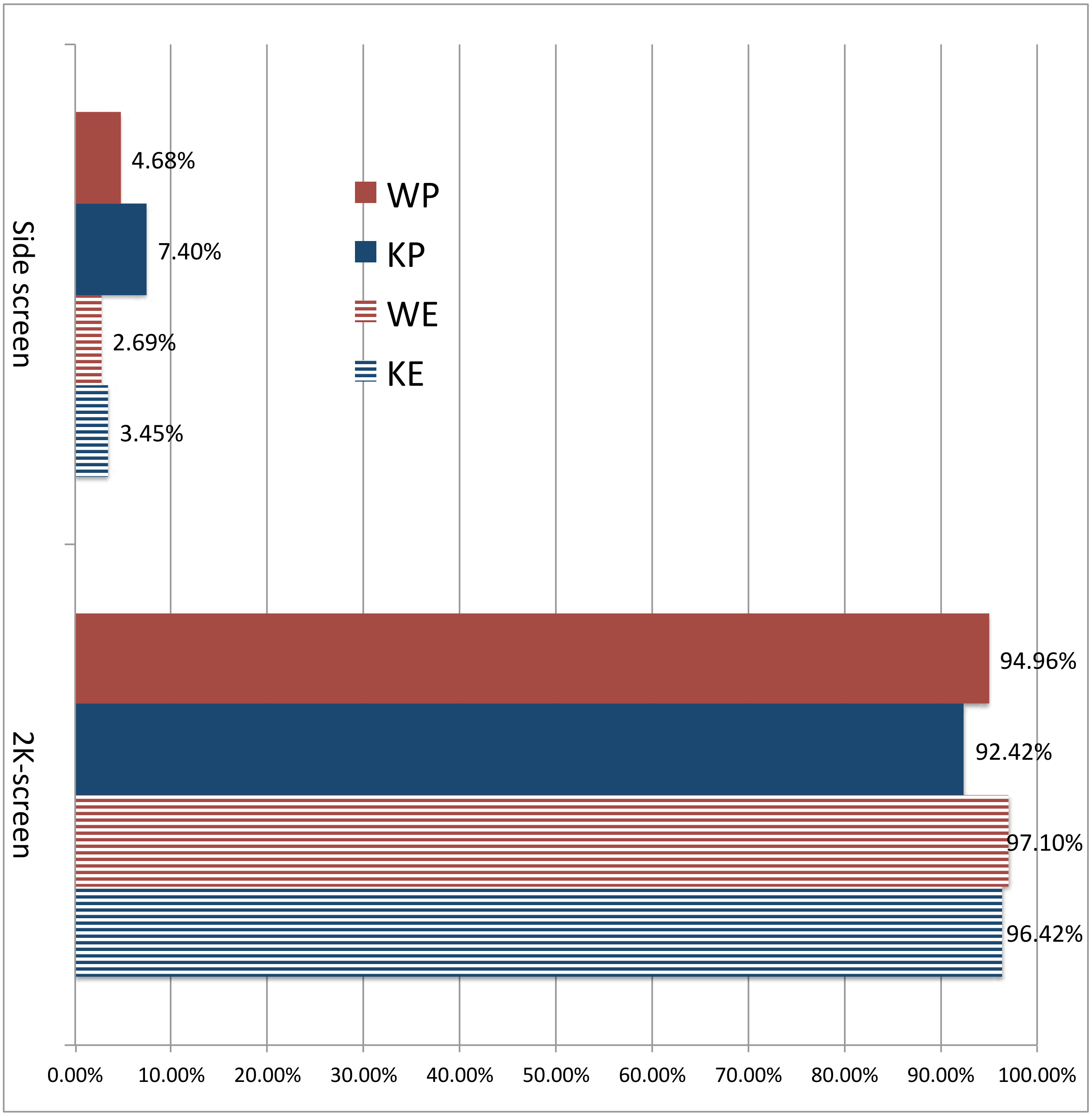

Figure 8. Diagram of W/P, K/P, W/E, K/E (4*3) divided over the ATC screens (main 2K screen, side screen). PLC (solid color) vs EXE (striped), W (red), K (blue).

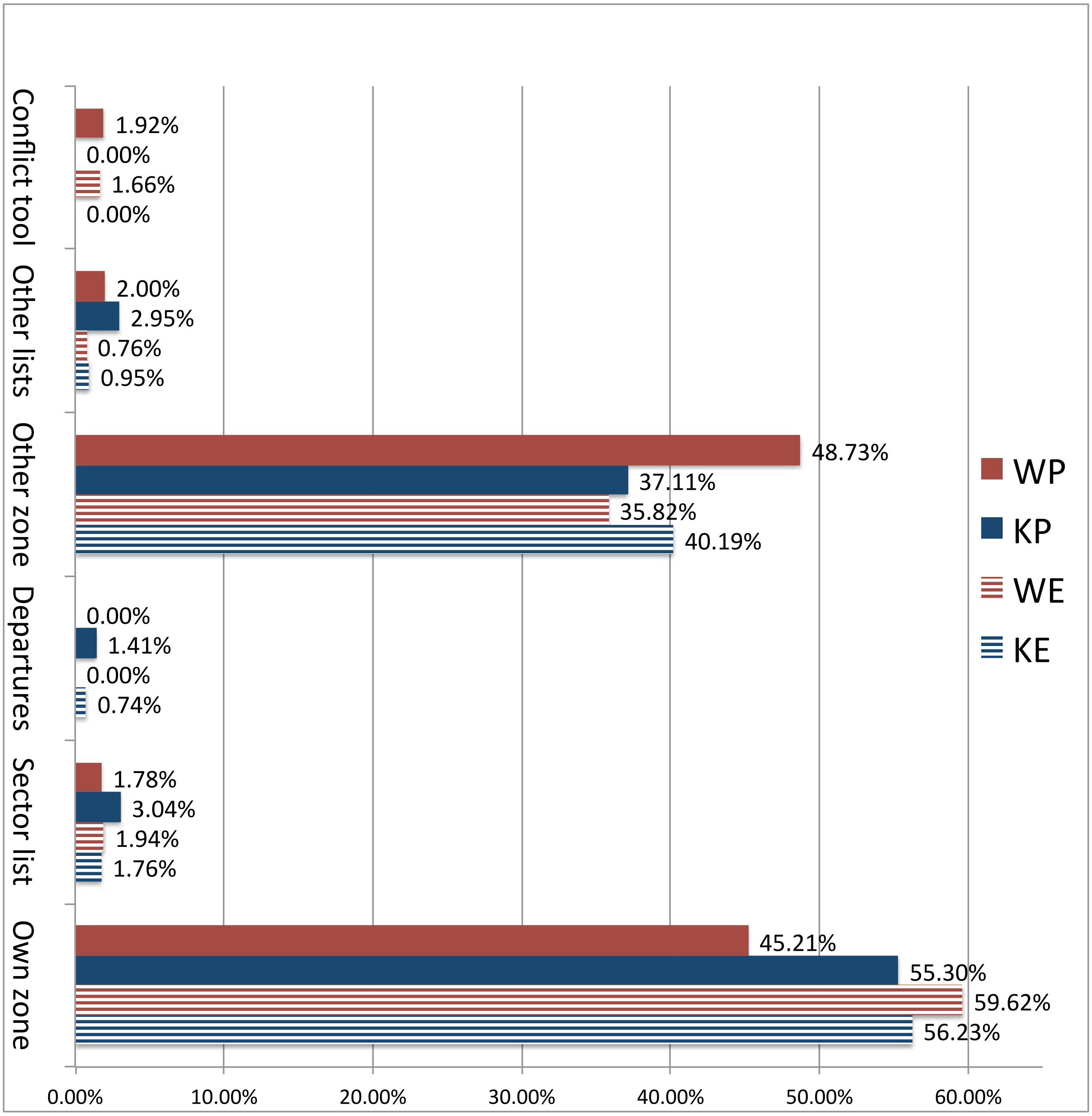

Figure 9. Diagram of W/P, K/P, W/E, K/E (4*3)divided over the ATC tools.

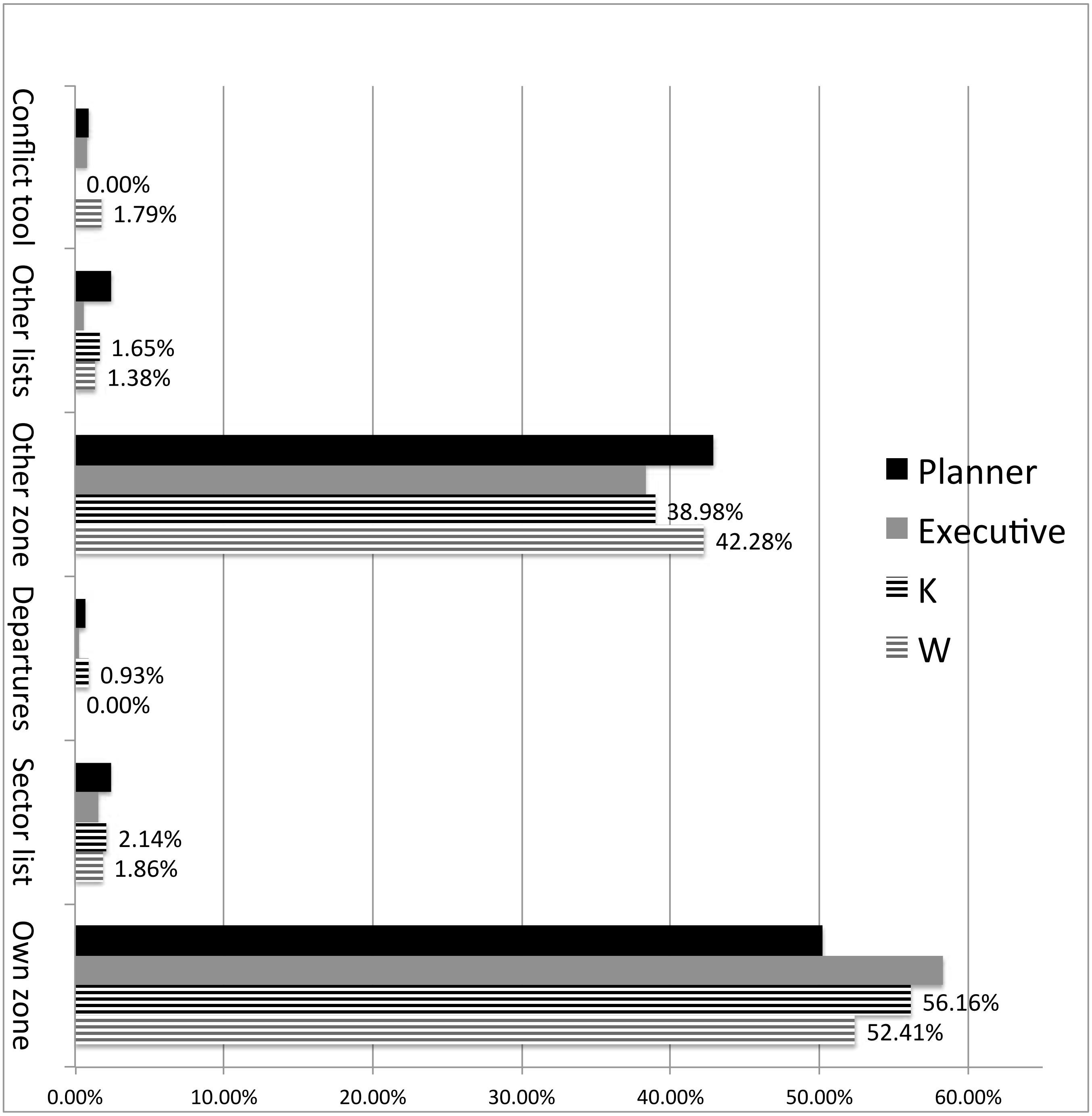

Figure 10. Combined diagram of split of into PLC versus EXE (2*6) (colored), and split into K versus W (striped) (2*6).

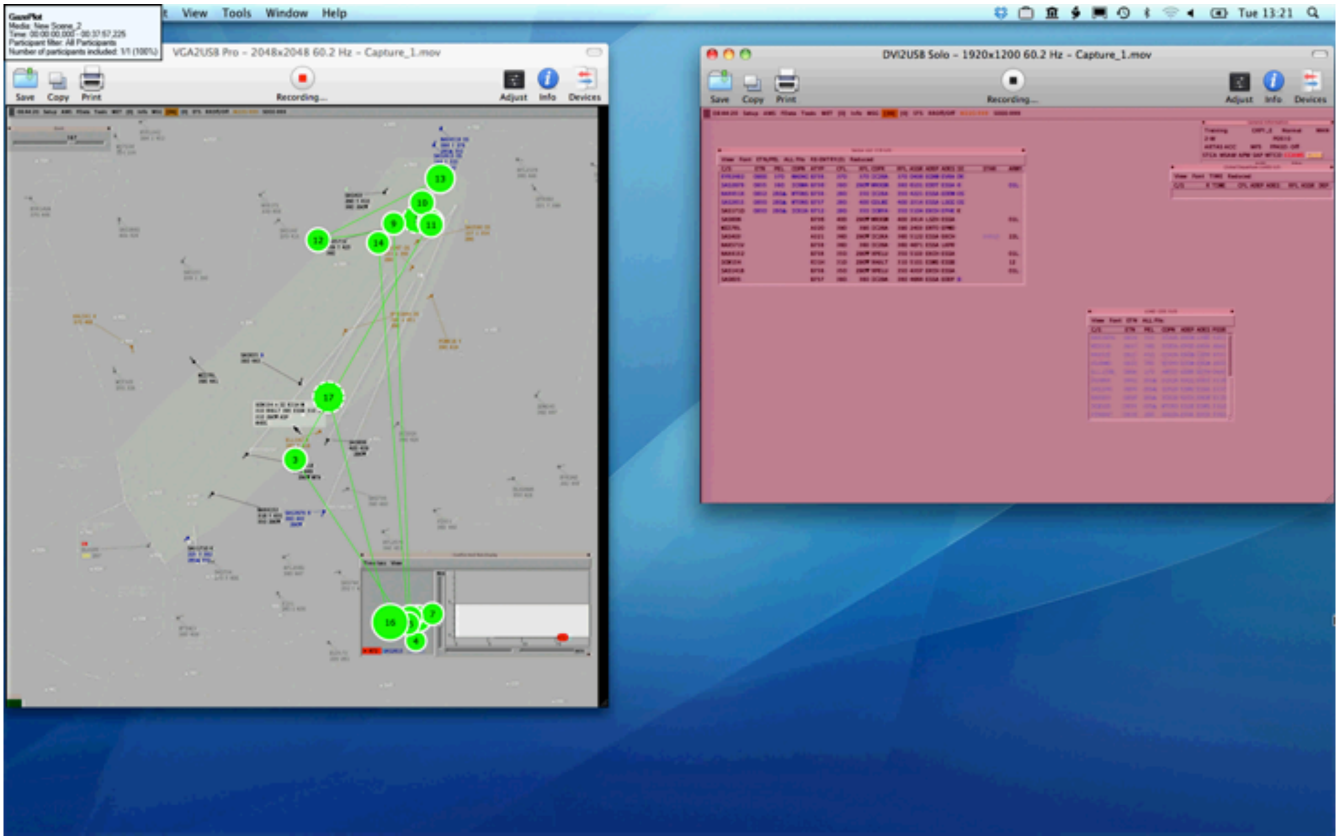

Figure 11. Conflict detection tool usage during five seconds of one run.

DISCUSSION / CONCLUSIONS

Our findings provide a possible explanation for why the conflict detection tool did not contribute to safety during the loss of separation events. As previous studies have shown, a higher amount of fixations is beneficial for detecting events during dynamic situations [5, 11]. Thus, each fixation should be made to count. However, the average visual scan speed (3 fixations / second, see results to question Q4), means that in situations with high visual workload, looking at the separation tool is actually a trade-off between continuing the own work with traffic guidance and spending fixations on the redundant traffic monitoring system (the medium term conflict detection tool, MTCD, which was used sparsely compared to the radar display, see results to questions Q1-Q3). On the one hand, the tool might help focus on the most important conflicts, but on the other hand focusing on the tool costs visual fixations.

To interpret a potential conflict, it is not sufficient to look only on the MTCD tool, which only presents what flights are involved, and the estimated separation and time to conflict. This is also reflected in that the MTCD tool is indeed only used as a supporting tool, with the main attention spent on the radar display (se results to Q1). The ATC therefore also has to locate the conflict on the radar tool to examine the conflict further. In case of a correct identification by the MTCD tool, this is time well spent. However, in case the identification was in error, it might in hindsight have been better to spend that time continuing the own scan pattern. Thus, this is clearly a tradeoff that depends on **a)** the visual workload of the controller, **b)** on whether the tool is usually correctly identifying conflicts, and **c)** on whether the tool complements the controller (by supporting detection of conflicts that are hard to detect for a human controller) or if it only is a redundant system (having the same strengths and weak detection points as the human).

That the MTCD tool is not seen as working well (is not used) in climb / descend areas) suggests that it might share weaknesses at least with the radar tool, which also presents horizontal separation more clearly than vertical separation (being in essence an x versus y scatter plot). It is possible to set the tool to highlight all conflicting aircraft on the radar screen, however if there are many conflicts, they will all be marked in the same way, which reduces the utility of that tool.

Substantial applied research is required to reach a higher level of understanding of how teamwork automation should be designed.

An in-depth study of fixation times is required, to examine whether there is information that takes unnecessarily long time to comprehend, or if there are interactions that require unnecessarily long times of visual attention. With interactions, we mean interface actions like setting aircraft altitudes in the radar tool.

Further, detailed data were collected for both the EXC and PLC on the usage of the conflict detection tools. This data will be analyzed and is the starting point for an in-depth study of the relative strengths and weaknesses of the MTCD tool ability to detect conflicts. Areas to evaluate are a) what must be done to make it more relevant or acceptable for climb/descend areas, and b) to what extent it complements the controller versus only acts as a redundant monitoring system. An episode analysis is needed to examine visual scan patterns that involve the MTCD tool. We suggest that analyses should firstly highlight the cost versus benefit of using the tool. Secondly, if the cost turns out to be high, it can be used a baseline for comparison with better tools. If the MTCD tool turns out to be hard to re-design to work with climb/descend areas, then research is needed to design, and experimentally evaluate new kinds of visualizations for conflict detection. For the episode analysis we intend to include situations with a high versus low amount of conflicts, that varies between high and low overall workload, e.g. measurable through pupil size [10], and high / low vigilance e.g. measurable through increased blink rates [9].

Furthermore, similar analyses are clearly needed to examine conflict detection capacity versus automation support in newly designed visual environments. Currently, in particular remote towers are an important new area where research could provide benefit through supporting and evaluating design of teamwork automation.

We have also observed, although this was not examined experimentally, that the controllers found the recording to be unobtrusive, meaning that they find it acceptable in regular training situations. Further, the experiment revealed few fixations on the eye tracker. Although, using the eye tracker, it was not possible to compare with a situation without an eye tracker in that position, so we do not know whether fixations would have been in that direction without the tracker.

The potential use of eye tracking recordings as a tool for direct feedback during controller training and the use of recordings of experienced controller visual scan patterns as training materials, could also be of value to examine further.

These results should furthermore be a driver for industry to explore possibilities for designing better automation tools, and by that improve performance, as a means to meet society and customers requirements.

In conclusion, this study has suggested a possible explanation for the loss of separation events, but also suggest that substantial further research is needed into teamwork automation. In particular, studies that use realistic traffic scenarios with experienced controllers are required.

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