Human-automation Collaboration Strategies

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Abstract—**This study describes human-automation collaboration strategies for detection and monitoring of conflicts in air traffic. Automation is represented by two medium term conflict detection tools in Air Traffic Management: the Conflict and Risk Display (CARD) and the Flight Leg Tool (FLEG). Qualitative and quantitative results from a field experiment during competence assurance are reported. A quantitative analysis based on eye tracking was conducted to examine the extent of visual attention to the tools. The qualitative analysis describes patterns of human-automation collaboration, of visual scan and tool usage. Implications of the human-automation collaboration strategies are discussed.**

Air Traffic Management Tools, Safety, Information Visualization, Situation Awareness, Automation, Eye tracking

I. INTRODUCTION

This paper is the second part (see also [1]) of a study on conflict management tools in Air Traffic Management (ATM), initiated to examine potential sources in ATM tools and practices of problems that resulted in separation minima infringements in the Swedish Air Space between 2011 and 2012. The infringements occurred either as violations of separation minima, or as very late detection requiring rapid action.

To detect conflicts in the airspace, area controllers can, on the one hand, use the main situation display (radar) to detect conflicts, through visually scanning the traffic on their own (strategy 1). On the other hand, they can also use conflict detection tools that predict and present infringements based on automated analyses of the traffic situation (strategy 2), including flights that are not yet visible on the radar. This tool can present conflicts in a separate window, but conflict detection tools are also integrated and available to use in the main situation display. Between the extremes of primarily relying on the own scan to detect conflicts, versus to rely primarily on the conflict detection tools, various intermediate strategies are possible. What strategies are used in practice is however currently uncertain. This uncertainty stems from e.g. two sources. Firstly, system designs are underspecified – usage procedures are not specified in detail. Secondly, humans adapt and adjust their work to circumstances at hand, which may result in a difference between procedures (work-as-imagined) and work-as-done. These adjustments may have beneficial characteristics (exhibiting resilience) or be detrimental (resulting in risk).

To understand human-automation collaboration in conflict detection in ATM, air traffic controllers were studied during competence assurance runs in an Air Traffic Control Center (ATCC). The first part of the study was reported in [1]. It showed that the detection tool presenting conflicts in a separate window was attended to visually (potentially for conflict detection), but did not show what role it played in conflict detection. It also showed that the main situation display (radar) was used the most. That the tool was used does thus not mean that it was the source for conflict detection – the controller may have already seen the conflict on the main situation display. Based on that overarching quantitative analysis, we could therefore not distinguish between strategies 1 and 2. Moreover, the first part showed that in practice there may (at times) be a trade-off between conducting an independent visual scan for conflicts on the main situation display, versus examining conflicts presented through the conflict detection tools. This is due to limited controller capacity for visually scanning information (each visual fixation takes time). Therefore it would not always be possible to use both systems redundantly, to both check all conflicts presented by the automation, and to simultaneously keep up an independent traffic scan. This is a factor that may give rise to diverging strategies. To gain a deeper understanding of human-collaboration in conflict detection, conflict episodes would have to be examined, which is the approach taken in this second part of the study.

We first present a more detailed quantitative account of the extent of tool usage (than in the first part of the study), including tools integrated in the main situation display, indicative of human-automation collaboration for conflict detection. We secondly present a qualitative analysis of tool usage episodes, describing patterns of human-automation collaboration, and discuss the implicit strategies that the patterns reflect.

II. THEORY

To make decisions, Air Traffic Controllers (ATCOs) must keep up with the changing traffic picture. This has been the focus of research for a long time, through the concept of Situation Awareness (SA) [2]. The modern approach to studying SA (see e.g. [2]) is to examine three facets: *SA states* (what goes on?), *SA processes* (of updating, maintaining, gaining SA), and *SA systems* (of agents and tools involved in the process).

SA states regards *objects* (e.g. aircraft and their status), *frames* (e.g. potential conflict scenarios), and *implications* (of

particular aircraft in particular situations with conflict potential), on a *horizon* of plans and developments (events). Traditionally it was the task of the ATCO to keep control of the SA state, with the support of basic tools such as paper flight strips, and radar images. In modern ATC systems, the controller is supported by more powerful tools to monitor air traffic.

The tools can be considered parts of an **SA system**, with the purpose of separating traffic while maintaining other ATM system objectives. Technically, the more advanced tools can be described in terms of **automation levels**, of support at different levels, or as dividing the work between human and automation at different levels [3]. In terms of levels of automation, the tools may support information acquisition at the lowest level. They may also, at a higher level, make inferences based on the data, such as predicting conflicts. At higher levels of automation than was used in this study, automation may also make decisions and execute actions (e.g. autopilots). In this study, all decisions were made by the ATCOs. Nevertheless, some automation activities provide redundancy, such as detecting conflicts based on traffic data. The findings that the automation makes based on its own inferences must then be communicated to the ATCO to be of any use.

The SA process concerns updating of SA for the system as a whole, from the perspective of the decision-making agent(s) in the system (i.e. the ATCO). This reflects a recent focus in academia on collaboration between human and machines, e.g. [4-7]. The focus is then on joint system performance, rather than on division of work. This has resulted in principles, such as: the use of pattern-based perceptually clear information, clear indications of changes, and taking into account the time spent on communicating and coordinating information between human and automation. ATM environments today are highly visual, and information dense. This means that principles such as those must be related to characteristics of the interactive visual presentations of the ATM environment, to understand how the SA process works through the SA system. The visual display of air traffic information can be characterized in term of information visualization principles. The respective principles are described below, in descriptions of the ATM system.

THE SA SYSTEM

A. Roles

In the area control center, Planning Controllers (PLC) and Executive Controllers (EXE) control the airspace, see Fig. 1. 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 EXE, 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 communicates with aircraft and issues the instructions needed to create a safe and orderly flow. In some cases the EXE and PLC uses the same tools to support decision making and planning and in some cases the usage of tools varies. The tools (automation) have no authority; the ATCOs make all decisions and are responsible also for conflict detection. The

EXE and PLC sit next to each other. The EXE, PLC and the available automation are in this context considered to be a team; hence the overall performance is dependent on these components and how well they collaborate.

The automation in focus in this study is the Medium Term Conflict Detection (MTCD). It uses information that the controllers have typed into the system. It notifies the controller of interactions that might require aircrafts to be re-planed, re-cleared or may affect the choice of clearances that occur up to 20 minutes before a potential infringement. Primarily, MTCD interacts with the controllers through two tools, CARD and FLEG (see below). Those two tools serves as the main interface to the conflict detection automation.

Figure 1. *ATCO work positions. Eye-tracker placement to the right.*

B. Main displays

As shown in Fig. 1, the controllers have four displays available. Of those, the two displays to the right are in focus in this study. The main situation display is the middle screen. The radar image is shown on this display, but other tools (lists, tools) can also be placed on it. The display to the right is used for lists and tools. As shown in part 1 of this study [1], the controllers focus on information on the main situation display. The information visualization principle *linked and coordinated views* [8] is implemented, so that information in all views about the same objects are always consistent. Further, *brushing* [9] is used, sot that if an aircraft is selected on the radar screen, it is also highlighted in various lists where it is represented.

C. Conflict and Risk Display (CARD) for MTCD

The Conflict and Risk Display (CARD, Figure 2) for MTCD alerts the controller about existing or pending conflicts. In supporting SA, CARD mainly presents framing (that a conflict may be on the horizon), and shows the time/distance aspects of the conflicting aircraft on the event horizon. However, it does not highlight particular implications for the specific objects involved beyond the duration of the conflict (indicated by lines from the points). CARD shows both a textual list of information (conflict pair callsigns) and a scatter plot (pointing out the predicted minimum distance (Y-axis) and the time remaining and duration of the situation (X-axis) of aircraft conflict pairs. CARD presents an alert in red if aircrafts are closer than 10 nautical miles. CARD can also be set to display potential but less likely conflicts in blue, but this mode was not used during the competence assurance runs.
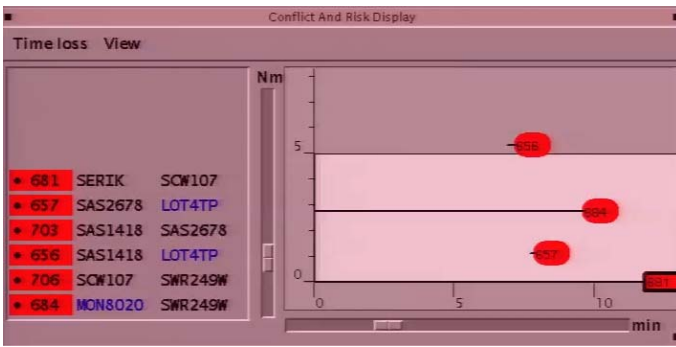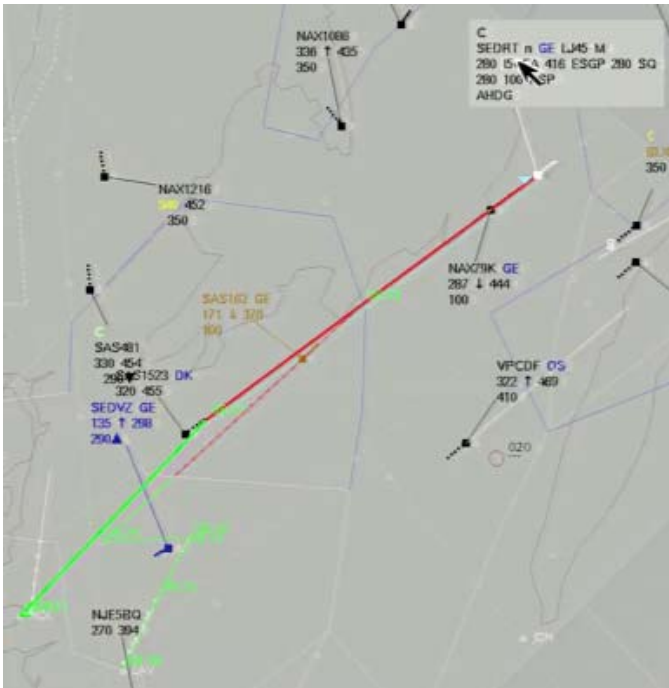
Figure 2. *CARD display for MTCD*

Figure 3. *FLEG display for MTCD*

It is known that CARD can present false MTCD alerts, i.e. that does not correspond with a situation that requires special attention. An example of a false alert could be about two aircrafts that are at the same flight-level, where MTCD has calculated that the two aircrafts will infringe on each other. However, MTCD may not take into account that one of the aircrafts flies slower than the other so that the infringement will not occur. This kind of alert that does not strictly require ATCO attention or action may nevertheless draw the controller's attention. The controller examines each alert to determine whether it represents a real threat, and if so also decides what action to take. In examining false alerts this represents inefficiency of the SA system, regarding human-automation collaboration.

D. MTCD indicators integrated in the main situation display

The MTCD system can be set to indicate conflicts integrated in the main situation display, on the radar, as red dots on aircrafts in conflict. In terms of information visualization [9], this exemplifies *brushing*, controlled by the automation. This was used by some of the controllers (for an example, see Fig. 5).

E. Fligth Leg (FLEG) for MTCD

The flight leg (FLEG) tool (Fig. 3) can be activated to examine particular flight routes. The visualization principle *detail on demand* [9] is thus used. FLEG displays information relevant to maintaining and gaining SA of the event horizon [2], regarding specific plans, and projected conflict events, relating them to specific aircraft. Mirroring the use of color in CARD, red line segments represents predicted conflicts, whereas blue segments indicate potential conflicts. Green segments do not contain any predicted conflicts. FLEG can show conflicts for aircraft that are not yet visible on the radar screen (e.g. but are shown on CARD). This may support prospective SA, to generate awareness of future conflicts along the event horizon.

FLEG can be activated from CARD, then indicating flight routes concerning the conflicting aircraft. FLEG can also be activated from the main situation display, then indicating flight routes concerning the particular selected aircraft.

III. DATA COLLECTION PROCEDURES

This section describes the procedures for data collection, which can also be found in [1], reporting part I of this study. 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, using the COOPANS platform (used in Sweden since 2005).

Each position consisted of one ATC Planner (PLC) and one ATC Executive (EXE). 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 (Fig. 1).

TABLE I.   ANALYZED EPISODES, MALE / FEMALE, AGE, EXPERIENCE, OVERFLIGHT OR CLIMB/DESCEND SECTOR, EXECUTIVE OR PLANNER POSITION, DURATION OF RECORDING IN SECONDS, TOOL USAGE.

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

A. Participants

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

B. Data collection procedure

During each run, gaze was recorded for one of the positions. A Tobii X300 Eye tracker 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 screens were split, with one signal pair passing through to the ATC screens, and the other signal was sent to the computer recording the eye movements on the displays. 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 quantitative analyses conducted for this paper. It was however taken into consideration during the qualitative episode analyses reported in this paper. Since the area was in essence concave, and the analysis software assumes a flat surface, some inaccuracies were induced. Further, since we covered an area outside of the design specifications of the Eye Tracker, the tracking was less accurate on the side screen, and on the lowest part of the main situation display. See [1] for further details on the procedure.

C. 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 (this variable was analyzed in [1]). The runs were divided into two scenarios: overflight sector and climb / descend sector. (See Table I). 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 I).

IV. QUANTITATIVE ANALYSIS

A quantitative analysis was conducted to gain an overview of the extent of tool usage in the experiment runs (CARD was used only in the overflight scenarios).

An initial analysis showed that in these runs, FLEG was actually not used much in the climb/descent scenarios when compared to the overflight scenarios. On average, FLEG was used about 10 times more in the CARD+FLEG (overflight) scenarios than in the FLEG only (climb/descend) scenarios Specifically, in the CARD+FLEG scenarios FLEG was fixated 115 times on average, compared to 9 fixations in the FLEG only scenarios (significant on the 5% level using a two-tailed T-test). In terms of percentages, in the CARD+FLEG scenario, FLEG was used between 1,9% and 4,2% with a mean of 2.7%. In the FLEG only scenarios, in contrast FLEG was used between 0 and 0,9% with a mean of 0,2%. In terms of visual load, the scenarios were similar (on average, the visual load in the CARD+FLEG scenario was 88% of the visual load of the FLEG only scenarios, with a mean of 4239 and 4793 fixations, respectively).

Based on this result, we decided to base our qualitative analysis on the CARD+FLEG scenarios, to understand how the tools were used in conflict detection.

V. QUALITATIVE EPISODE ANALYSIS

Eight episodes of CARD and FLEG usage were identified for qualitative analysis from the six overflight runs were CARD was used. Episodes are numbered to correspond to participant numbers, letters (a/b) are used to distinguish between several episodes for the same participant (see Table I). Episodes are also marked with their respective roles (executive, EXE; planning controller, PLC). Each episode was defined by an MTCD alert in CARD. Episodes are analyzed based on a) overarching events, e.g. activation of FLEG, conflicts becoming visible on CARD, and on b) gaze sequences. In each of the figures in this section, colored circles connected by lines represent fixations. In particular, the number of lines going into CARD tool indicates how many times the ATCO had to return to it during the episode.

A. The Human checks a conflict on CARD, and then immediately examines it through FLEG

Two episodes illustrate usage of the FLEG tool to examine a conflict directly after a fixation on CARD, exemplifying automation-driven conflict detection and management.
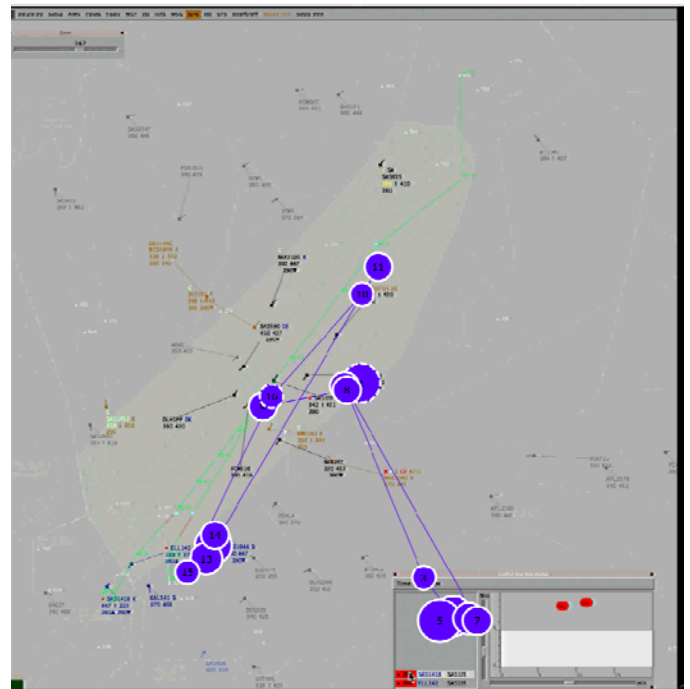

Figure 4. *EXE, 5s, 14 fixations. Gaze plot of episode 1.1b.*

In episode 1.1b (Fig, 4), CARD showed two conflicts (SAS1418-SAS105, ELL142-SAS105), between the 5 and 15-minute tick marks, and above the 5nm (white) zone. The conflicts appeared on CARD, and were shown on FLEG, at 8.27.10, after data entry regarding SAS105, on the main situation display. The aircraft SAS105 and SAS1418 were marked with red dots on the radar image by the automation. At this point, ELL142 was not yet visible on the radar display. It appeared on the radar at 8.28.10, marked with a red dot.

Our analysis (Fig. 4) illustrates how the SAS1418-SAS105 conflict was examined after attending to CARD at 8.28.30. The plot shows that the gaze pattern went from CARD, to SAS1018, and then followed the FLEG lines (see a close-up of the FLEG lines in Fig. 5).

Figure 5.   *The SAS1418 - SAS105 conflict (episode 1.1b) in FLEG.*

Episode 2.4 (Fig. 6) shows a more complex situation, with four simultaneous conflicts, of which two involve the aircraft LOT4TP. The top conflict in the CARD plot (in focus in this episode) above 5mn (the white area) was between the 5 and 10-minute tick marks. The three conflicts below were within 5nm, of which two were within 5-10 minutes.
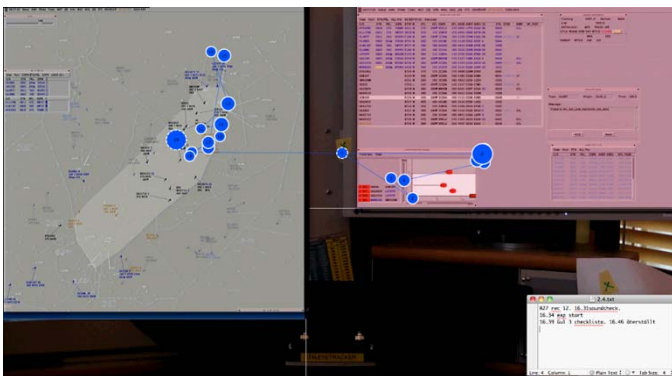

Figure 6.   *PLC, 6s, 19 fixations. Gaze plot of episode 2.4. SAS1418 is in the mid of the sector, LOT4TP at the top edge of the sector.*

This situation was first examined through CARD, via several fixations. The ATCO then activated FLEG, to scan the sector from the mid of the sector (the location of SAS1418, highlighted in CARD), upwards to the area of LOT4TP, back to the mid of the sector (several fixations).

B.   *Conflict detection and monitoring not driven by CARD*

In contrast, the in the following episodes, CARD had a minor role, illustrating conflict detection driven by independent controller air traffic scan.
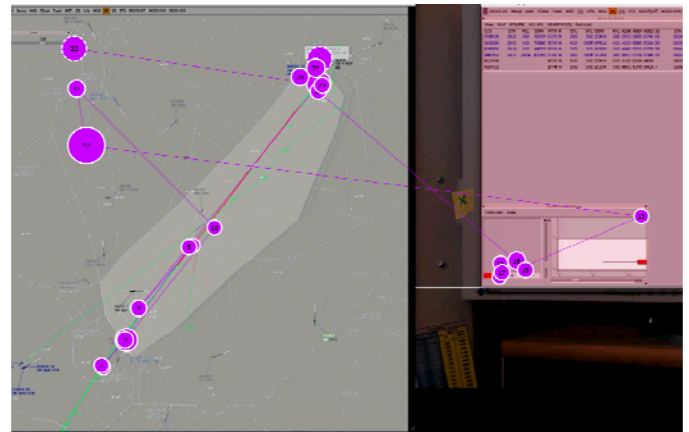

Figure 7.   *Gaze plot of episode 2.3a.*

In episode 2.3a (Fig. 7), BMR362 and DLH1PF appeared in the control zone at 8.02.00 (without "red dot" markers activated"). This conflict was indicated as within 5nm with a long duration, nearly 15 minutes ahead. The ATCO examined the conflict later through FLEG, at 08.03.30 being busy monitoring traffic at the other end of the control zone. After checking the conflict, the ATCO attended to CARD.
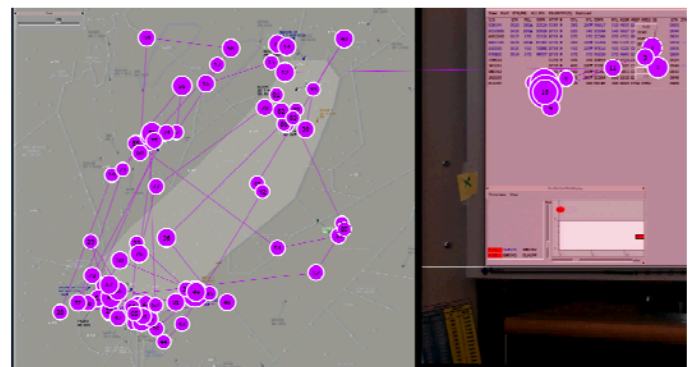

Figure 8.   *PLC. Gaze plot of episode 2.3b. Independent scan of air traffic between CARD alert of BMR362-SCW144, and re-checking of the conflict 40 seconds later.*

In episode 2.3b (Fig. 8), at 8.10.00 the ATCO activated FLEG, and examined a conflict regarding BMR362 and DLH1PF. The "red dot" conflict markers were not in use. At the time, FLEG also showed a conflict between BMR362 and SCW144. However, the eye-tracking plot indicates that only the BMR362-DLH1PF conflict was examined at this time, since visual fixations are only present along that part of the FLEG.

At 8.11.50 the controller glanced at an alert from CARD regarding the (already examined) BMR362 and DLH1PF conflict. However, then the ATCO did not examine the BMR362 and DLH1PF conflict again, but instead examined the FLEG of SCW144. This time eye tracking data indicates that the BMR362-SCW144 conflict was actually examined. Further, at 8.12.10 this conflict between BMR362 and

SCW144 was shown in CARD, in the mid of the 5 nm range, at the farther end of the 10- min tick mark. After 40 seconds, this conflict was checked (again) through FLEG, but without any fixations on CARD. Between the alert and the FLEG check, the ATCO monitored traffic using the radar image (Fig 8).

This suggests that the ATCO airspace monitoring was not driven by the alerts from CARD, and that no unexpected developments were shown there during the check at 8.11.50.

C. Delay between CARD alert and ATCO attention to CARD, with a subsequent check through FLEG.

One episode illustrates a delay in examining a conflict displayed in CARD (Fig. 9). Episode 1.2a starts with an alert from CARD between SAS2615 and SCW105, indicating an infringement around the 15-minute tick mark. At this time, SAS2615 entered the radar image near the top of the sector (SCW105 was not yet visible on the radar). The ATCO scanned the air space for about 48 seconds (Fig. 9) from the CARD alert, including the area of SAS2615 before attending to CARD. Then (Fig. 10) FLEG was activated from CARD, indicating the conflict on the main situation display, which was examined. Afterwards FLEG was also activated from the radar screen, also indicating an additional blue (less likely) conflict with another aircraft. This FLEG line was also examined.

Although there was a delay before attending to the conflict in CARD and examining it through FLEG, in this episode there was a considerable amount of time before the predicted occurrence.
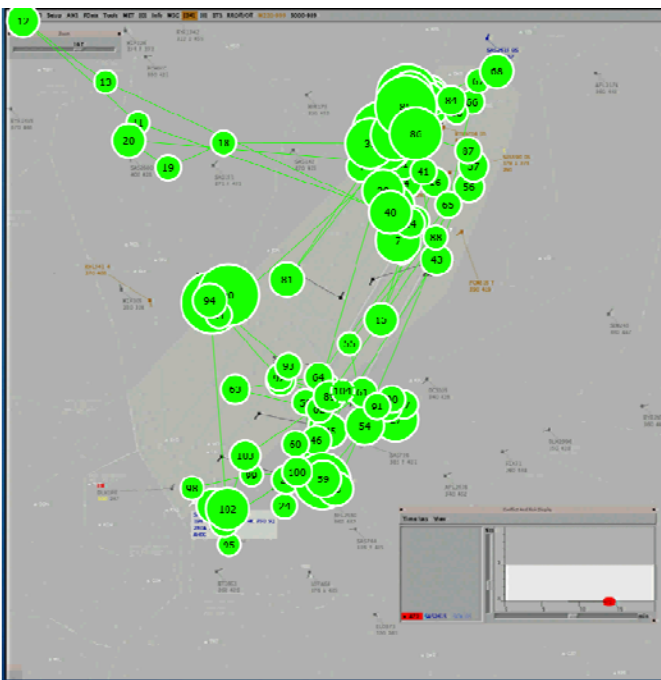

Figure 9.   EXE, 48s, Gaze plot of episode 1.2a, unattended CARD alert. The "red dot" conflict markers were not in use. (red is used in the display for the chracters "EM" in the lower left area)
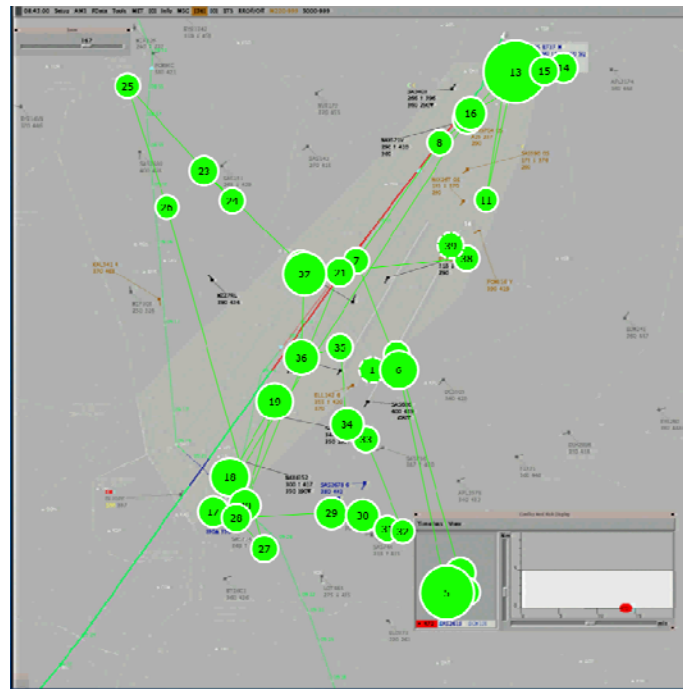

Figure 10. EXE, 11.5s, 39 fixations. Gaze plot of episode 1.2a, after attending to CARD.

D. Examination of a predicted infringement through CARD and FLEG in the near future (within 5 minutes)

Illustrating automation-driven conflict detection in a situation requiring relatively rapid action, one episode from the same scenario as Case C, shows an infringement within 5 minutes.
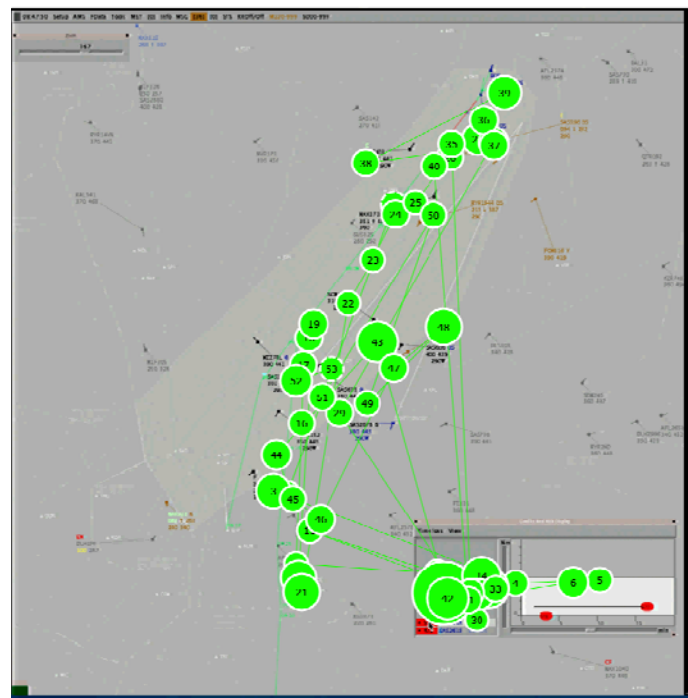

Figure 11. EXE, 16s, 53 fixations. Gaze plot of episode 1.2b. The most critical conflict is at the top of the sector. The "red dot" conflict markers were not in use

Episode 1.2b, Fig. 11 starts with a CARD alert between NAX45X and SERIK at the top of the sector, indicating an infringement within the 0-5 minute tick marks. A less urgent conflict was also shown. Just before this episode, the ATCO had attended to NAX45X, at which time the conflict was just below the 5nm mark. The controller looked at CARD several times during this episode. The scan (Fig. 11) started with examining CARD through several fixations, then checking an aircraft (within the not-yet-displayed FLEG lines, far from the urgent conflict occurrence, next to CARD). The ATCO then followed the FLEG lines for the more urgent conflict. The ATCO returned to CARD, examined the second (less urgent) conflict in CARD, then through FLEG.

E.   Continous monitoring of conflicts ahead through CARD

In contrast to taking rapid action on an imminent conflict, one episode exemplifies CARD usage to get an early warning of conflicts, and to monitor them continuously.

In episode 1.1a (Fig. 12), a conflict between DLH1PF and BMR362 was shown on CARD, on 8.2.20. It was immediately checked in FLEG, although none of the aircraft are yet visible on the radar. It was indicated in CARD as a conflict with a long duration (a long line stretching out from the conflict), at close range, but a while ahead, around 15 minutes ahead. DLH1PF and BMR362 finally appeared on the radar at 8.6.10 with "red dots" from the MTCD system, and were immediately checked in CARD and FLEG. The conflict was then closing in on the 10-minute tick mark on CARD, but still as an infringement warning with a long duration. The ATCO first examined DLH1PF, then BMR362 through FLEG. In this situation, the MTCD tools usage clearly resulted in high prospective SA for the upcoming conflict.
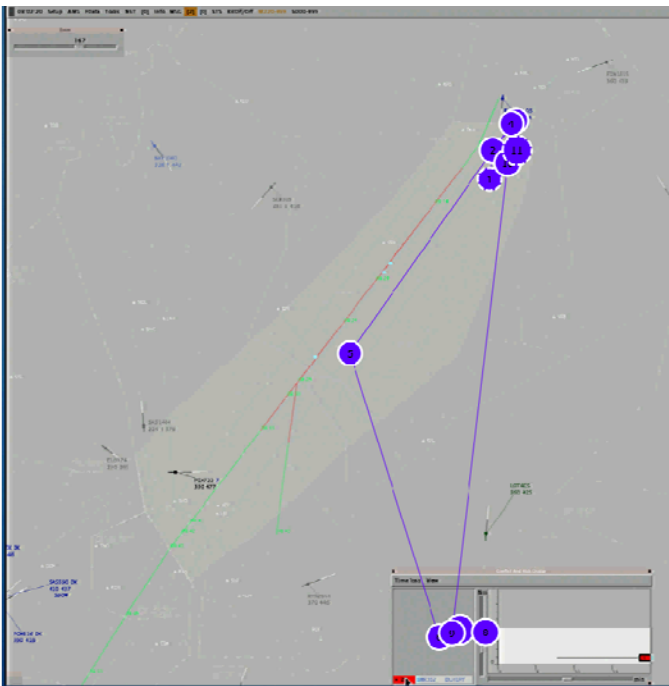

Figure 12. *EXE, Gaze plot of episode 1.1a, when the conflict first emerges*

Similarly, in episode 3.1 (Fig. 13), the ATCO re-checked a previously examined conflict (between BMR362 and DHL1PF,

an infringement around 15 minutes ahead). After examining the situation in CARD (Fig. 13), using several fixations, the ATCO continued the air traffic scan before exploring the conflict through FLEG. It is thus important to differentiate this kind of re-check during monitoring (when the ATCO may already be aware of the nature of the conflict, through previous examinations of the conflict), from initial checks of a conflict.
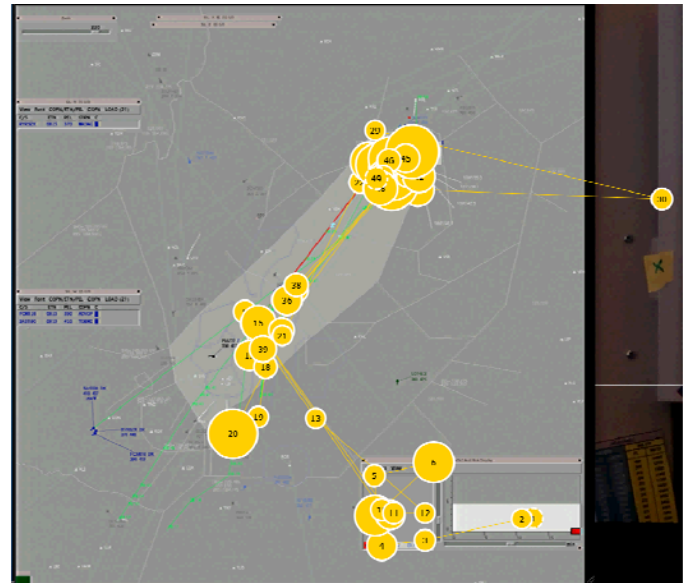

Figure 13. *PLC, 24s, 49 fixations. Gaze plot of episode 3.1. The "red dots" for MTCD alerts were activated.*

VI.   Discussion

In this parallel mixed method study of *human-automation collaboration strategies for conflict detection in ATM*, variability in tool usage was found: a) regarding whether higher-level automation tools (MTCD) were used at all b) in placement of CARD on the main situation display versus the secondary screen, c) regarding usage of the "red dots", and d) in the degree of influence of Medium-Term Conflict Detection (MTCD) tools on visual scan patterns. That the controllers in the climb/descent competence assurance runs only used on low-level automation (integrating information in the main situation/radar display), should serve as a reminder that higher-level automation is not yet used everywhere in ATM.

The variation in tool usage that was found in the qualitative analysis reinforces the importance of the initial question in this paper: *to what extent is human and automation involved in conflict management?* Specifically, the analysis highlighted patterns of human-automation collaboration reflecting the variation in tool usage, ranging from strategy 1 (independent controller scan) and strategy 2 (conflict detection departing from tool alerts). Interestingly, intermediate strategies were also found, related to specific tools/interface elements. These will now be discussed, in relation to the visual interface elements of the automation that were involved in the visual scan patterns.

A.   Conflict and Risk Display (CARD) for MTCD

The qualitative analysis has shown two main, contrasting, patterns of CARD usage, as part of the SA system,

corresponding to two extremes (strategy 1 and 2) of human-automation collaboration.

Firstly, integrating CARD tightly in monitoring work (Case A / strategy 1), with the tools having a major impact on the ATCO SA process. (Note that the effectiveness of this strategy depends on the effectiveness of MTCD.) This pattern involves the following items: attending to CARD, activating FLEG, examining the conflict, and deactivating FLEG. What is indicative of this episode type is:

a) That the ATCO reacts to MTCD alerts quickly, by attending to CARD quickly after an alert is visible.

b) Examination of conflicts indicated in CARD through FLEG immediately after attending to CARD, rather than continuing the own independent scan pattern

c) The usage of "red dots", allowing the ATCO to quickly spot MTCD alerts during regular traffic scans, without focusing on CARD.

Secondly, in the contrasting episode type (Case B / strategy 2), the ATCO mainly scans the traffic independently of CARD, checking CARD now and then (as a redundant SA system agent). The automation was nevertheless not affecting ATCO scan patterns extensively. In Case B, MTCD alerts were not immediately attended to and examined through FLEG (thus does not immediately disrupt the own visual scan).

Case E exhibits a complex visual scan pattern, partly similar to Case B. It is a case where some involved aircraft are initially not shown on the radar display, and conflicts therefore cannot be detected through regular scans of currently visible traffic, but can still be examined through the MTCD system. In this case, the ATCO already has high SA of the event when it becomes visible on the main situation display. Although the visual scan pattern may therefore resemble Case B when the other aircraft emerges, the ATCO has already examined this conflict when aircraft become visible on the radar display. Case E illustrates one of the main benefits of the MTCD system, to be able to detect conflicts long before their potential occurrence, and to monitor them continuously as long as they are a threat. Thus, it is not as simple as saying that one of the strategies used in A or B is better than the other. This should also be taken into account in future studies – each case/episode must be related to the whole scenario (over a longer time), and cannot be analyzed in isolation.

B. Flight Leg (FLEG) for MTCD

The quantitative analysis of FLEG usage in this study indicated that it was used together with CARD. The episode analysis showed how: through FLEG, the ATCO examines predicted conflict events shown in CARD, along the event horizon. CARD mediates the implication (conflict) and event horizon facets (distance, time): This is however insufficient not only in theory, but also in practice, to judge the specifics of conflicts or to manage plans. This requires the use of CARD combined with FLEG (plan aspect of the event horizon, indicating potential conflict events, relations between conflict pairs). This suggests that the information visualization could be improved, to strengthen human-automation collaboration.

C. RED DOTS (conflict alerts) for MTCD

When the "red dots" (see Fig. 5) are not in use, ATCO are required to look at the CARD tool, or to activate FLEG for each aircraft in a round-robin strategy, to see what conflicts are predicted by the MTCD automation. As suggested by our analysis of Case C, not using the red dots may result in a delay in detecting conflicts (i.e. increased performance variability). In contrast, when the dots are in use, the ATCO may become aware of conflicts by observing the dots during regular scans of the air traffic on the radar display (Case A). Case D exemplifies an episode with a shorter time-to-conflict than in Case C. If the negative aspects of those two cases were to coincide (a lack of time, a delay in detection due to a pre-occupation with other aircraft), this could result in a separation infringement.

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