Attention Distribution and Trust in Higher Levels of Automation within Air Traffic Control

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***Abstract*— Air traffic control (ATC) is constantly changing and developing to handle more traffic and increase fuel efficiency among aircrafts, but still maintain a highly safe environment. The levels of automation are increasing to respond to the new demands and challenges, but this comes with an uncertainty for the automation behavior. Situation awareness and attention distribution for the operators are important factors to maintaining control and trust within automation. This paper presents findings from one case study including distributed attention and trust in automation within ATC. An approach on how to investigate trust in higher levels of automation is then proposed. Further, this paper will also present an approach on how to proceed with future research in this area, and the importance of investigating trust in automation and levels of automation in all domains of air traffic control.**

Keywords-component; air traffic control, levels of automation, attention distribution, trust in automation

I. Introduction

The next generation air traffic control systems are here; remote towers controlling airports several miles away and control centres with higher automation and decision-support tools. This article will present the results from a SESAR validation showing air traffic control operators' (ATCO) trust in automation. Strategic conformance, the degree to which automation's behaviour matches with the humans behaviour, has shown to be an important construct for ATCOs using new automation [1]. This paper will contribute to the understanding of the importance of human-automation collaboration in air traffic control, and propose an approach for innovative research in that area.

The levels of automation [2, 3] increases with more technology in ATC and mode awareness [4] is a priority for all ATCOs nowadays. Parasuraman, et al. [5] proposed an extension to the levels of automation concept to four information processing stages, which all have its own level of automation scale similar to the once proposed by Endsley and Kaber [6] and Endsley and Kiris [7]. With more automation the ATCO get a more monitoring role instead of performance role and high focus lays on situation awareness [8, 9]. If the automation in some way fails outside the knowledge of the operator, he/she will fail to detect it and fail to take over control [10]. The ATCO need to have situation awareness constantly, build frames around the situation, know what's going to happen, how to act if something unpredictable happens [9] and gain trust for the automation.

II. Background

Automation has developed over the years to cooperate with the operator to maintain the operators' involvement in the processes and system performance, which also leads to a lower risk of out-of-the-loop-problem [7]. Automation has been seen as more of an either way system; either the automation takes on the task or the human takes on the task [6]. However, the levels of automation increases within ATC with more decision-support tools. Adaptive automation [11] is the process of control that must go back and forth between the human and the automation over time, depending on the demands of the situation, to increase human performance. In air traffic control, this means the ATCO needs to know what the system is going to produce, receive feedback and decision-support from it and then provide an output to the system and pilot, and this continues in a loop back and forth.

It has been assumed that human operators can't be trusted in high controlling complex processes [12] but now it's more the trust in automation the problems addresses [13]. Trust can, for example, affect how operators rely on and accept automated systems [14]. In human-machine interaction trust can be defined as "the attitude that an agent will help achieve an individual's goals in a situation characterised by uncertainty and vulnerability" [15]. In this definition, an agent can be either automation or a human. If the industry can't build automated systems that can be trusted it means we can't build supervisory control systems at all [10]. Trust in automation is the key to its usefulness [16]. However, it's important to separate interpersonal trust from trust in machines [17] and this article will only refer to trust in machines. Barber [18] defines trust as three expectations; 1) our general expectation of the persistence of the natural physical order, the natural biological order and the moral social order, 2) our specific expectations of technically component role performance from those involved with us in social relationships and systems, 3) our specific expectations that partners in an interaction will carry out their fiduciary obligations and responsibilities, that is, their duty in certain situations to place others' interests before their own [10, 18]. All three expectations are applicable to the ATC system where the operator is in interplay with other operators, the system/automation and pilots who works to create a safe and trustworthy environment.

The competence of the automation is an important aspect of human-machine trust and has been confirmed by two experiments by Muir [19]. Since these experiments are from the 1990th it is of great interest to see how the ATCOs in today's environment experience trust in automation when it comes to new technology and to remotely controlled airports. It is also of interest to investigate the different modes of trust [17] there are in air traffic control.

Chavaillaz, et al. [20] showed that reduced system reliability resulted in lower levels of trust towards the automation. The participants could adjust the level of automation (5 levels) but chose to have a higher level (around 4). This contradicts with other findings which found that participants prefer having manual control [19, 21].

Previous research therefore does not confirm whether an operator prefers having manual control or feels comfortable with automation in more control. With more and more technology in the everyday life, the opinion about automation and automated control may change. Operators seem more open to the idea of more automation, which is verified in the study described below.

III. Early Results

This chapter will present the early results from a case study in a SESAR validation, in an air traffic control centre, where trust in automation was evaluated. The levels of automation are increasing constantly with new remote towers. Also for the en-route and TMA operators, where new tools are introduced, to ease the ATCO's decision-making to decrease their workload. The case study presented below investigated the en-route controllers' trust in higher levels of automation and how the controllers adapt to the automation.

A. Method

Through a collaboration between several organisations, including LFV Air Navigation Services of Sweden, SESAR, Thales and Airbus, a validation was conducted in an air traffic control centre simulator. The validation was done with the next automated tools in ATC; an extension of the arrival management system (AMAN) which includes Controlled Time of Arrival (CTA) [22] and data linked communication (i4D). The participants in the validation have been working as ATCOs for many years and were familiar with the CPDLC-function. The participants had two weeks of training in the simulator, in which the validation would be held, before the validation started to get to know the system and functions, how to interact with it and to be familiar with the environment. The validation consisted of two weeks, with three runs per day. Every run was 1 hour and 30 minutes long. At the start of the validation, all the participants were familiar with the system and had built up a trust for the concept and methods.

A case study with an eye-tracker took place in the validation, to be able to follow the ATCO's attention and work with the new tools. By only using the existing data collection methods used in the validation (raw data from computers, questionnaires, pulse rates and debriefings) the information from the participants' eye-movements and to be able to map their attention would have been lost. The eye-tracker was calibrated for every run. The participants stated during the training, before the validation, that they were not bothered by the tracker during their job.

Two experienced ATCOs participated in the case study, one sector was used and the participants were the ATCO every other scenario (three scenarios, a total of six runs). The focus during the test was on one aircraft that always appeared in the scenarios. The first scenario was a baseline with no CTA-procedures (a variant of the ATC system used in today's operations in Sweden with no CTA or i4D). The other two scenarios were solution scenarios in which the aircraft was equipped with i4D.

B. Results and discussion

The eye-tracking data indicates that the participants had trust in the higher levels of automation compared to baseline, they allowed the automation to do the procedures for them by using the CTA-method. The ATCOs also distributed their attention to the objects that needed their attention and actions instead of focusing on the aircrafts that used the CTA-method. The following sections discuss these results in detail.

The participants had fewer interactions with the aircraft which was i4D equipped. The number of total interactions is calculated by how many times the ATCO spoke to the aircraft, looked at it, interacted with it or in some way gave attention to it. In the baseline scenario, the ATCOs gave directions (by oral communication) to the pilot for the aircraft 12 and 9 times. In the solution scenario (with i4D) they gave instructions 3 and 1 times for scenario 2 and 3 and 3 times for scenario 3. It is clear that the ATCO had more interactions with the aircraft if it was not equipped with i4D. For the baseline the ATCOs interacted with the aircraft a total of 149 times and 69 times compared to the two solution scenarios, which had 41 and 39 interactions and 45 and 48 interactions. When the aircraft was equipped with i4D, the ATCO did not spend the same amount of time focusing on that aircraft compared to the baseline. These results indicate that the automation allows the ATCO to distribute the attention to other aircrafts when the specific one in the solution scenarios had i4D.

The CTA-method is more efficient compared to the baseline and this is also demonstrated by the comments the ATCOs provided in the questionnaires. An example is the question "This week you have been working with different mixes of aircraft equipage. Please describe your opinion about this". The answers highlight that CTA reduced workload. In response, one ACTO wrote "From the exercises I feel it is clear that more air traffic and more complex sequences can be handled if there is a higher number of i4D equipped aircrafts".

The ATCOs felt a lower level of coordination during the scenarios with i4D compared to the baseline, which indicates that the automation helps the ATCO with some coordination. The ATCOs experienced a lower level of workload compared to their day to day work when the aircrafts had i4D and that they could predict and be ahead of traffic more than in the baseline scenario. This means they were able to plan their work better with aircrafts equipped with i4D, compared to baseline, and able to see how the situation would evolve. The ATCOs were satisfied with the level of control they experienced during the scenarios. They were more satisfied with the level of control in the baseline compared to the scenarios with i4D, but they felt the required level of coordination as lower during the scenarios with i4D. The ATCOs thought they felt confident working with the AMAN system, and that the i4D allowed them to handle more traffic. The ATCOs could distribute their attention to something more important if the aircraft was equipped with i4D, i.e. if the aircraft had a higher level of automation. The ATCOs also stated their trust in the system and that they could handle more traffic with a higher level of automation.

This result goes in line with the results from Chavaillaz, et al. [20], where the participants preferred a higher level of automation if they could choose. This indicates that a higher level of automation is more appropriate and acceptable among the operators in a work environment that demands a high workload and that the operators feel comfortable with it to handle a higher amount of traffic. The ATCO and automation are in some way adaptive and when the CTA-procedures are used automation works in favour for the ATCO, which leads to a decreased workload. However, when something unpredicted happened, as strong wind, the CTA was cancelled. The ATCO nor the automation adapted or shared control, it was either way. Therefore, the trust in automation when it comes to higher levels of automation, such as multiple remote towers and more automated decision-support tools in area control, must be investigated further. An approach to this will be presented below.

IV. Approach

To investigate the attention distribution [23] for ATCOs through different levels of automation in air traffic control centers, towers, remote towers and multiple remote towers, both empirical case studies, simulator studies and lab-environment studies will be conducted. The foundation lays in the theory of levels of automation, distributed attention and situation awareness with the main focus on safety in high complex systems.

Several previous studies have already been conducted about human-machine collaboration strategies within ATC to see how the ATCOs distribute their attention [24-26] but also on teamwork and how to improvise and work “as it happens” [27].

The work of an ATCO is very complex and there is a lot going on at the same time. They are always working “as is happens”, therefore it can be very hard to only observe their job, have interviews or look at raw data from computers to follow their attention and understand it. To understand more of the ATCOs’ work, how they distribute their attention, an eye-tracker can be an effective tool to use. One of the most valuable and useful tools the ATCOs has is the eyes, which they use to comprehend what is going on in their surroundings. With an eye-tracker, the eye-movements of the ATCO becomes visible and can show what and how long the ATCO looks at something on the different screens and what tools they are using.

We move our eyes in a particular direction of interest to make a part of the visual field in high resolution, this so we can see in fine detail on the object we want to look at. The gaze almost always moves to the point we think are the most interesting and since it is possible to track the eye-movements, then we can track the path of the person’s attention. This can provide information about the person’s situation awareness processes and what the they choose to focus their attention on. [28].

Combining eye-tracking with several other methods such as interviews, questionnaires, observations and pulse rate data, attention distribution and different kinds of working behaviours can be mapped. How the ATCOs handle stress and higher levels of automation can also be explored with eye-tracking. The eye-tracking data can be used to design new decision-making tools, since the data will show what the ATCO normally looks at, which tools the ATCO do and do not utilize. Too much information can confuse the user [29] and the eye-tracker can help the identification of tools that draws too much of unnecessary attention, this to make the job of the ATCO more efficient, reduce workload and at the same time maintain trust. According to Duchowski [28] there are at least three research domains that stand to benefit from eye-tracking: visual perception, human-computer interaction and computer graphics. With the use of eye-trackers several kind of stimulus can be presented to the participant or use the real world as stimulus (for example the ATCO’s screens). The output can be used in several ways such as; timeline visualizations, attention maps and scan path visualization to name a few [30].

Further research in levels of automation and trust in automation will be completed in air traffic control, with the use of eye-tracking combined with other methods, to examine the differences between centers, towers and multiple remote towers. The results from the study in the section above showed that the operators could and felt confidence in handling a higher amount of traffic, if there was a higher level of automation. This means that it is important with collaboration practices that enforce trust. To be able to delegate the work between operator and automation, trust must be built and the right amount of level of trust must be incorporated in the right situation. Too much trust can be of disfavor for the operator and if the automation will fail the operator must know how to act and why. It must be a collaboration between the operator and the automation, both need to know what the other can handle, when to interfere and take over control when the other fail. Teamwork must be built, with strategic conformance. As Dekker and Woods [31] state, it is no longer a question about who has control over what, rather how do they get along together. This is something that needs to be considered when designing the new remote towers in the next generation of control management systems.

It is also of interest to investigate the different levels of automation when something in the situation goes wrong or if something unpredicted happens. For example, the CTA-method used in the previous study showed that when a strong wind hit a sector, or many conflicts between aircrafts appear, the time over the metering fix is canceled and the ATCO goes back to normal basic procedures. This is also the results of a study made by Ruff, et al. [32]; when the user experienced decision-aiding error, the trust for the automation decreased. There is a need for clear directions and indications for how much the automation can handle before the ATCO needs to take control. And when it happens the ATCO need to have the proper situation awareness, distribute the attention and feel trust for collaboration with the system.

Trust in higher levels of automation are of priority and with eye-tracking the attention span can be mapped to investigate when and where automation can be in control. With more automation there can be a reduction in workload, optimized workflow, reduced fuel efficiency, longer trajectory predictions, while still maintaining a high safety system. But for this, teamwork, strong collaboration and trust are needed between the members of the system.

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