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Automation Transparency and Personalized Decision Support: Air Traffic Controller Interaction with a Resolution Advisory System ⋆

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Abstract: In order to satisfy future air travel demands, there is a need for a more automated and modernized air traffic control. Automation is expected to advance from its current principal utilization as software tools to become an autonomous agent cooperating with the air traffic controller. To facilitate interchangeable, functional and sustainable human-automation collaboration, there is a need to develop better interaction and visualization techniques. Ultimately, automation might be rejected because of the system's opacity (what is it doing and why?) or mismatch in underlying strategy (I would solve this problem differently). Human-machine cooperation is believed to benefit from automation sensitive and adaptive to individual preferences in problem solving. Furthermore, increased transparency afforded by a decision-aid in regards to its reasoning and problem solving, can positively influence user attitudes including acceptance and trust. In a recent study we hypothesized that both these factors (strategic conformance and interface representation transparency), would influence task performance and willingness to use an automated decision aid in a conflict detection and resolution task. Nine controller trainees participated in two real-time simulations in which they were tasked with directing traffic and maintaining separation in short en-route traffic scenarios. Results showed that controllers perceived and used the two interface representations differently. Even though controllers accepted conformal solutions more often than nonconformal, with a degree similar to what has been observed in previous studies, the effect of strategic conformance was not significant. These findings are discussed in relation to the challenges in diffusion and acceptance of decision-aiding automation.

Keywords: Air traffic control, automation, decision making, decision support systems, display design, human-machine interaction, transparency, strategic conformance

1. INTRODUCTION

The advancement of technology is significantly changing how we interact, communicate and utilize automation. Like many complex and time-critical domains, air traffic control (ATC) is facing a fundamental modernization that builds on the use of more advanced automation. The current function allocation based relationship between controller and machine is envisioned to evolve to a more fluid, continuous and mutually coordinated team relationship. Consequently, the controller is expected to assume a supervisory and monitoring role, while relinquishing much of the tactical "hands-on" tasks to automation. ATC automation, in turn, is expected to grow in intelligence and its cognitive abilities to become more of a team member providing decision support. In association to these changes, one of the most pressing human factors challenges is how we can design automation that is embraced, accepted and trusted by the controller.

The MUFASA (Multidimensional Framework for Advanced SESAR Automation) project, hypothesized that decision support conformal to an controller's problem solving style benefits task performance and acceptance of automation. This was investigated by varying the conformance of a decision support system providing conflict resolution advisories. Controllers accepted conformal advisories (i.e., advisories based on their own unique conflict solving style) more often, gave them higher agreement ratings, and responded faster, than with nonconformal advisories based on a colleagues contrasting but workable and safe conflict solution style (Hilburn et al., 2014). In 25% of cases, however, controllers disagreed with their own conformal advisories. Participants had difficulties understanding resolution advisories and specifically which aircraft were in conflict. These findings made us consider characteristics of the interface as contributory to advisory rejections. Possibly, controllers rejected advisories because of the interface's lack of *transparency*, preventing adequate understanding of what the automation was suggesting.

The aim of this study was to replicate and extend the MUFASA project reported in Hilburn et al. (2014), by investigating how the automation transparency, together with strategic conformance of resolution advisories, affected conflict resolution per-

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formance and automation acceptance. We focus specifically on the theoretical underpinnings, and experimental investigation, of automation transparency.

In Section 2 we address the transparency afforded by automation information displays and visualizations. Guidance and conclusions on best practices drawn from the review are used to inform the development of a more transparent version of the interface representation used in the MUFASA simulator (Section 3). Section 4 details the method used to examine the effects of transparency on controllers' acceptance and performance in real-time simulations, as well as controllers' perceptions of transparency. Results from the simulation and associated questionnaires are presented in Section 5. Finally, Section 6 discusses implications of the results in relation to challenges in acceptance and diffusion of decision support automation.

2. AUTOMATION TRANSPARENCY

Previous research has indicated that acceptance and trust in automation can suffer because of the system's opacity (*what is it doing?*) (Christoffersen and Woods, 2002; Sarter et al., 1997) or mismatch in underlying strategy (*I would solve this problem differently*) (Hilburn et al., 2014; Westin et al., 2016). Automation surprises, resulting from the automation not performing as expected, or acts in a way not anticipated (and not commanded), have been associated with several "out-of-the-loop" human factors issues (Sarter et al., 1997). One particularly relevant visualization and display design challenge, addressing these issues, is that of automation transparency (Cramer et al., 2008; Höök, 2000), also referred to as automation visibility (Dudley et al., 2014), and comprehensibility (Jameson, 2008).

Generally, automation transparency reflects the automation's ability to afford understanding and predictions about its behavior. It is a measure of the automation's openness in information communicated, through the interface, to the operator: *what* the automation is currently doing, *which* information is being used, *how* it is being processed, and *when* it is provided. Specifically for decision support systems, design decisions have to be made regarding how much, and in what ways, information should be provided about the criteria, uncertainty, and rationale underlying automation's judgments and problem solving (Bass and Pritchett, 2008).

One common method for increasing automation transparency consists of providing explanations underlying the automation's behavior. Such recommender systems have been extensively applied in the context of e-commerce and semantic web services, diagnostics applications in healthcare, and museums and cultural institutions to enhance user interaction and experience (e.g., Cramer et al., 2008; Jameson, 2008). These typically consist of providing an argument for why the user should accept an recommendation, for example by comparing it with previous choices, or things that users with similar preferences have chosen, or that a certain item is believed to match the user's characteristics especially well for some reason.

More transparent interfaces are believed to increase decision-making effectiveness (good decisions) and efficiency (faster decisions), while also resulting in more predictable behavior of the automation. Researchers have attributed benefits of increased transparency on the acceptance (Cramer et al., 2008; Jameson, 2008), trust (Lee and See, 2004), and evaluation of advisory provided by decision support automation (Cramer et al., 2008). Although well-designed explanations can foster acceptance and trust, as an unwanted side effect, it can conceal automation errors (Dzindolet et al., 2003). Additionally, poorly designed explanations can obstruct understanding and counteract acceptance of recommendations (Herlocker et al., 2004). Increasing transparency by providing more information, can be a potential issue if the amount of information exceeds what the operator is capable to process within a certain amount of time (Marois and Ivanoff, 2005), and can cause display cluttering (Moacdieh and Sarter, 2015).

Ideally, increased transparency should be attained by integrating visibility information with automation outputs themselves to reduce operator information processing demands (Letsu-Dake et al., 2015). This is something that can be achieved through Ecological Interface Design (EID, Vicente and Rasmussen, 1992), which strives to reduce cognitive load in problem solving by organizing information in ways that explicitly reveals the constraints and possibilities of the environment relevant to a specific task (Borst et al., 2015). The constraints, and how they can be avoided, provides an explanation underlying the proposed behavior of automation, which can be especially useful in CD&R problem-solving that lack "gold standard" criteria for identification of optimal solutions.

3. TOWARDS A MORE TRANSPARENT INTERFACE REPRESENTATION

In the original MUFASA simulator, traffic was controlled using the EID inspired Solution Space Diagram (SSD), a novel CD&R interface prototype under development at Delft University of Technology. The SSD provides a tactical CD&R decision support tool displaying a selected aircraft's maneuverability constraints, based on the relative position of other aircraft (Mercado Velasco et al., 2010). The relative position of an "intruder" aircraft is visualized in the selected aircraft's control space (represented by the speed envelope) by processing velocity plane information of both aircraft, in relation to the minimum separation zone (typically 5 NM in en-route) of the intruder aircraft. The visualized maneuver constraint is shaped as a triangle formed by the tangent lines of the protected zone. To solve or avoid conflict, the controller only has to make sure that the selected aircraft's velocity vector is outside the constrained triangle shaped "no-go" zone of the intruder aircraft.

The SSD had the following key characteristics: A) It was integrated with the radar plan view display and appeared instantly around an aircraft when selected, allowing the controller to directly relate conflict zones to spatial positions in the speed and heading domain. B) The control space was restricted to a "heading band" (HB) representation limited to the selected aircraft's current speed. C) Finally, color-coded no-go zones provided information on separation loss proximity, with yellow (1-4 minutes) and red (less than 1 minute).

We believe that controllers might have rejected their own advisories because they did not understand resolution advisories, and that this lack of understanding partly was attributed to a shortage of information afforded by the interface representation (i.e., HB representation). While post-simulation questionnaire responses suggest that participants understood which information was used and how it was reflected in the interface, they found it difficult to extract specific information to help them identify the aircraft in conflict. As such, the interface represen-