Mismatches between Automation and Human Strategies: An Investigation into Future Air Traffic Management (ATM) Decision Aiding

Carl Westin and Brian Hilburn
Center for Human Performance Research, CHPR BV
Voorburg, The Netherlands
carl@chpr.nl, brian@chpr.nl

Clark Borst
Control and Simulation Division
Delft University of Technology
Delft, The Netherlands
c.borst@tudelft.nl

***Foreword*—This paper describes a project that is part of SESAR Workpackage E, which is addressing long-term and innovative research. The project was started early 2011 so this description is limited to an outline of the project objectives augmented by some early findings.**

***Abstract*—The Multidimensional Framework for Advanced SESAR Automation (MUFASA) project is exploring issues concerning the acceptance and usage of advanced decision aiding automation. Through a series of planned human-in-the-loop simulations, it aims to examine the interactive effects of automation level, air traffic complexity and strategic conformance (i.e. the fit between human and machine strategies) on automation usage. This paper outlines the theoretical background, experimental design and methodological approach underlying this effort.**

Keywords- automation, air traffic, acceptance, strategy, decision aiding, SESAR, complexity.

I. INTRODUCTION

Future Air Traffic Management (ATM) will have to rely on more, and more sophisticated, automation to accommodate predicted air traffic. This belief is captured in the SESAR programme's definition of five operational *Service Levels* [1], which are intended to guide the evolution from current to far-term European ATM operations. These five Service Levels assume increasingly greater performance requirements and greater information sharing between all stakeholders, and can be roughly categorised as follows:

- <u>Levels 0 and 1</u> are similar to current day, and may incorporate complexity management and route allocation tools, as well as airspace re-categorisation and harmonisation;
- <u>Level 2</u> will introduce free routing in upper airspace, as well as improve the accuracy of arrival and departure procedures in terminal airspace;
- <u>Level 3</u> will increase air-ground data exchange, and introduce advanced controller tools to support trajectory-based operations; and
- <u>Levels 4 and 5</u> will feature increased trajectory accuracy, and incrementally add airborne separation assurance.

At the heart of SESAR's five Service Levels is the expectation that automation will become more advanced in terms of the types of tasks it can perform, and the level of authority and autonomy it can assume. This notion of *Levels of Automation* is captured in various taxonomies that place automation on a continuum from fully manual to fully automatic as shown in Figure 1 [2].

Over the years, several broad concerns have been raised about over reliance on automation in such complex human-machine systems as ATM. Whereas automation has provided a number of benefits (e.g. cost, efficiency, safety) in a number of domains, its injudicious use has also been associated with a variety of human performance problems,

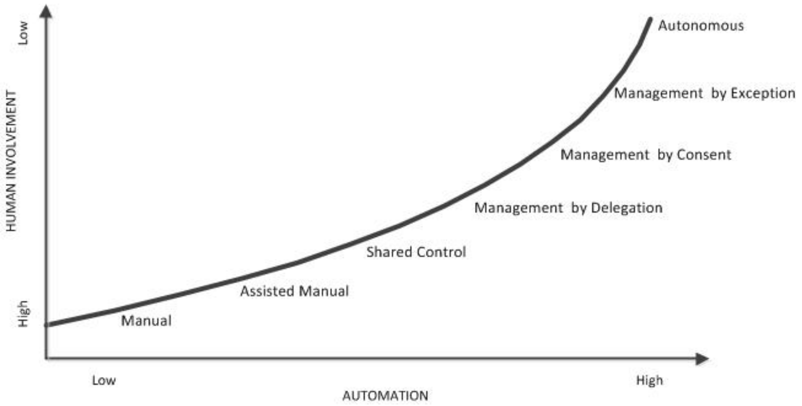


Figure 1 Levels of Automation.

including "out-of-the-loop" situation awareness and vigilance decrements, transient workload peaks, loss of manual skills, and decreased job satisfaction.

Given that the business, performance and regulatory frameworks of the SESAR ATM Target Concept all point to the need for more advanced automation, it is essential to adequately address as early as possible how such automation should be designed. Though automation design will present technical, operational and even legal challenges, some of the greatest challenges faced will be those having to do with Human Factors, and with designing automation in such a way that it retains the human as the centre of the future ATM system.

For instance, how do we build such automation in a way that keeps controllers involved and motivated? How do we define the functional roles of the human and machine in the far term? Will controller acceptance jeopardise the introduction of sophisticated automation? These questions are far from trivial, and if left unanswered threaten the planned evolution toward a mature SESAR concept of operations.

II. THE MUFASA PROJECT

Against the backdrop of these large questions, the *Multi-dimensional Framework for Advanced SESAR Automation* (MUFASA) project has recently set out to explore some of the issues surrounding advanced ATM automation. MUFASA recently kicked off as a SESAR WP-E innovative research effort, and collaborators include CHPR BV (NL), the Irish Aviation Authority IAA (EI), Lockheed Martin UK IS&S Ltd (GB), and the Technical University of Delft (NL). The project aims to develop a framework for future levels of ATM automation. This framework is to be built on a combination of empirical and analytical work, with the end goal being to help refine automation strategies and principles for mid and far term SESAR concepts. Specifically, the project aims to conduct a series of human-in-the-loop simulations of increasing fidelity to explore the potential interaction of three main factors:

- *Levels of Automation*,
- *Air traffic complexity*, and
- *Strategic conformance* – i.e., the extent to which automation's performance and underlying processes are similar to those of the human.

Whereas there has been a great deal of empirical and theoretical work into the first two factors, much less has been done in the area of strategic conformance. Paradoxically, this could in future become the most critical issue of all, as mismatches between human and machine could threaten initial acceptance of advanced automation. The MUFASA project is setting out to explore how the interactions between these three factors might impact acceptance and usage patterns associated with advanced ATM decision aiding automation.

This paper describes the results of the project's work to date, including literature review, scenario selection and experimental design, and lays out the approach for conducting human-in-the-loop simulations over the coming 20 months.

III. PREDICTIVE MODEL OF AUTOMATION USAGE

As an initial step toward experimental design, the project began with a literature review of over 280 primary sources, mainly in the areas of human factors, ATM operations and research, and CD&R design [3].

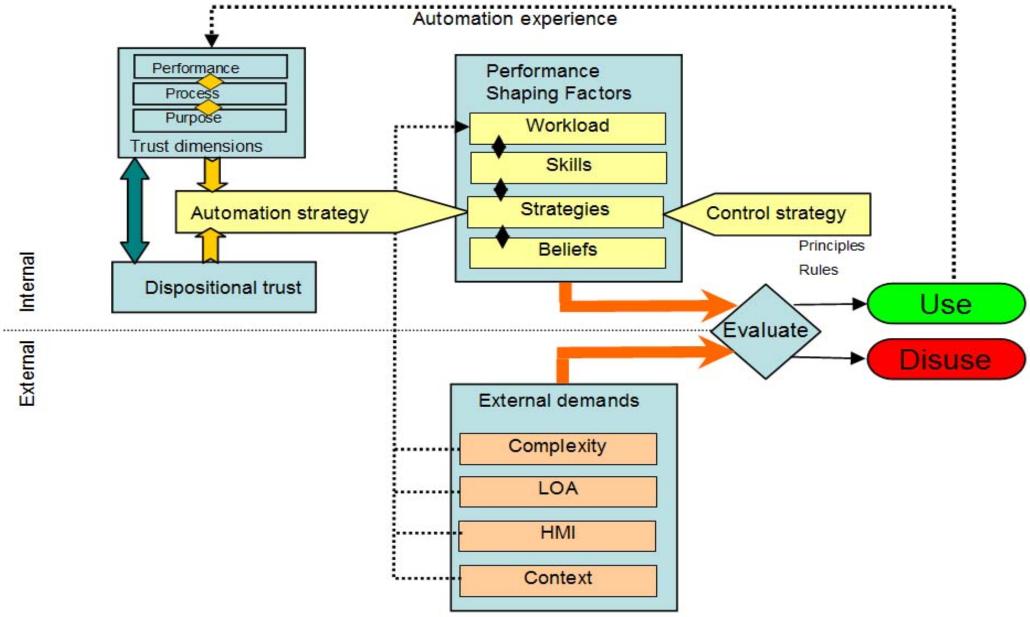


Figure 2 The MUFASA provisional predictive model of automation usage.

This review set out to cover empirical and theoretical evidence into the three main factors of automation level, air traffic complexity, and strategic conformance. This effort led us to a provisional model of automation usage, based on literature into controller strategies, automation trust, workload, complexity and automated assistance.

As shown in Figure 2 the decision to use automation or not is shaped by both internal and external factors.[1] According to this model, controller workload is an internal ”performance shaping factor” that interacts with such other factors as controller skill. Moreover, workload is the internal response to air traffic complexity, the level of automated assistance, and the HMI (and its associated costs and benefits), as well as other more contextual factors. A controller’s strategies consist of both control strategies (the so-called rules of air traffic control) as well as strategies relating to automation usage, in particular the degree of trust placed in automation.

Trust, in turn, consists of both dynamic aspects relating to the controller’s view of automation performance, process and purpose, as well as a more static ”dispositional” trust that a given individual by nature tends to place in automation. Together, these internal reactions and external demands drive the evaluation of the perceived benefit of automation usage, and ultimately drive the decision of whether to use automation. If used, automation's performance will feed back into the controller’s assessment of automation performance. Although this functional model is admittedly simple, it allows us to make some specific predictions about the types of automation usage patterns we might expect.

IV. CASE STUDY: THE ERASMUS PROJECT

The En-Route Air Traffic Soft Management Ultimate System project (ERASMUS) was a recent European Commission funded effort to demonstrate the potential benefits of strategic (> 15 min look ahead) de-confliction capability, using automated and slight speed adjustments, which were imperceptible to the controller [4]. The so-called *trajectory control by speed adjustment* (TC-SA) concept was developed for en route airspace, in which current-day controllers tend not to use speed adjustments. The ERASMUS approach can be summed up as follows:

”… Speed variation could be applied within a range of 10% without being significantly noticed by the controllers… These actions are assumed not to require the controller’s attention because they do not interfere with the controller’s activity, their decisions, or their responsibilities.”

ERASMUS took a decidedly technology-driven approach, by presuming that controllers do not need to know about automated inputs (in this case slight speed adjustments) upstream. Results from the project were encouraging with respect to conflict reduction– again, unresolved conflicts were reduced by up to 80%. However, the TC-SA capability was not able to prevent all types of conflicts. Results also showed that controllers were not bothered by the lack of TC-SA awareness. In fact, half of the controllers questioned the need for access to the underlying automation logic.

ERASMUS seemed to start from the premise that controller acceptance would not be jeopardised by automation whose activity is not even apparent to the controller. Although this seems logical (how could one object to things of which they are not aware?), it begs the question of why we should even consider controller acceptance of such automation.

Whereas the TC-SA concept is a valuable one in terms of concept exploration and ATM efficiency, it presents at least one theoretical complication that the current project sought to avoid, namely: automation was performing in a realm that by definition was not accessible to the human operator. That is, en route speed corrections can be subtle and beyond the ability of the controller to evaluate. In this case, the system is in fact performing a qualitatively different task than that performed by the human. As described later, MUFASA instead asks the question “*what happens to acceptance when human and machine are performing the outwardly identical[2] task*?”

V. RESEARCH QUESTIONS

The main aim of the MUFASA project is to investigate the possibility that controllers will show a systematic and *dispositional* distrust [5] toward automation, which could jeopardise the introduction of advanced forms of ATM automation in the future. Specifically, *will controllers be accepting of automation that is designed to replace aspects of their strategic decision-making in the areas of conflict detection and resolution*? The CORA project some years ago attempted to develop such automation [6,7], and evaluate a prototype version using controllers in human-in-the-loop simulations. Specific research questions to be addressed in the MUFASA project include the following:

- Will automation show expected workload benefits with increased traffic complexity and task load?
- Will automation costs accrue under low levels of complexity?
- Will acceptance and usage of automation show a similar pattern, in that they increase with traffic complexity?

---

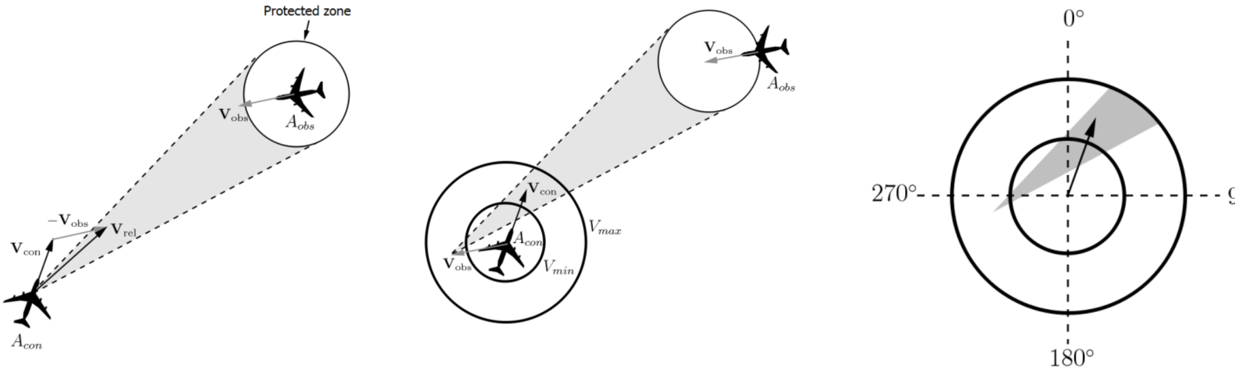
[1] The binary decision to use automation or not is an obvious simplification, and it might be more appropriate to incorporate a continuous response (e.g. “willingness to use automation”).

[2] External similarity is not the same as similarity of underlying process. Automation algorithms are not visible from the visible result. In this sense, though, human-automation interaction is no different than most human-human interaction.

- Are there automation costs, in terms of disuse and decreased acceptance, strictly on the basis of strategic conformance?
- Are there any interactions between strategic conformance, level of automation and traffic complexity?

VI. EXPERIMENTAL TESTBED: THE SOLUTION SPACE DIAGRAM

The Technical University of Delft (TUD) has for some time been carrying out R&D into innovative display concepts for CD&R. One such display is the Solution Space Diagram (SSD) which aims to represent an aircraft's control space in terms of speed and heading [8]. The solution space concept assumes that conflicts between aircraft can be observed easily in the (relative) velocity plane. Consider the situation with two conflicting aircraft, one being the controlled aircraft A_{con} and the other being the observed aircraft A_{obs}, as depicted in the three panels of Figure 3.



(a) Conflict geometry in relative space

(b) Conflict geometry in absolute space

(c) Solution space diagram for the controlled aircraft A_{con}

Figure 3 The Solution Space Diagram (SSD) concept.

The circle around A_{obs} is the separation minimum, or protected zone, that must not be violated. By applying vector calculus the relative velocity vector $\boldsymbol{V}_{rel}$ can be constructed. If the two aircraft are in conflict, the relative velocity vector lies within the triangle formed by the tangent lines of the protected zone surrounding the observed aircraft. By superimposing the velocity constraints of the controlled aircraft (as shown in panel c), an air traffic controller would be able to see the possible speed and heading opportunities, that is, the solution space that would resolve the separation conflict.

The SSD is currently being modified to represent different levels of automation. The current version of the SSD can be classified as a high level Stage 1 and Stage 2 automation [9]. Notice that in this case automation can be tailored to either suggest areas in which a vector solution should be found, or suggest a single specific vector command, or even execute an option (with or without the controller's consent).

Notice that SSD modifications are aimed at display changes to accommodate different levels of automation. The underlying automation function itself will be simulated, using the captured and replayed performance of controllers, as described in section VII.

MUFASA will extend the capabilities and application of TUD's ATM simulation and display work. The project will modify the capabilities to incorporate a higher level of command authority, which not only presents resolution space but also suggests a resolution vector. This extension of the SSD display capability with automated solutions provides the opportunity to systematically evaluate and compare algorithmic and heuristic approaches. That is, by modifying the simulation capabilities we can specifically address the issue of strategic conformance, and whether automated solutions fit with those of the human.

VII. EXPERIMENTAL DESIGN

Although the CORA project recognised the potential value of *heuristic* (as opposed algorithmic) resolutions, and matching automation strategies and working methods to those of the controller, its experimental design was necessarily limited by the fact that one could never ensure complete harmony between automation and human solutions. The MUFASA project has taken a slightly different approach, to first address the more underlying issue of whether such harmony would guarantee controller acceptance.

The method for doing this in fact involves presenting to controllers as "automated" solutions, unrecognisable replays of either their own solution (i.e. a *conformal* solution) or a colleague's slightly different solution (i.e., *non-conformal*). Assuming controllers remain consistent in their solution choice over time, this allows us to experimentally manipulate conformance between human and (simulated) machine solutions. This replay procedure is inspired by one used many years ago, with which it was shown that operators might be more likely to find fault with automation than with their own performance-- even when "automation" is an unrecognisable replay of their own performance [10].

As shown in figure 4, a series of three human-in-the-loop simulations is planned. This series will iteratively refine the SSD concept, as well as simulation capability and realism of the experimental protocol. Notice that initial part task simulations with university students will scale up for later simulations with en route controllers. Simulations are currently planned to use a 2x2x2 within subjects design[3], as follows:

- Level of automation (LOA) – Manual (display only) vs. resolution advisory;
- Complexity – air traffic complexity will be defined as Low vs. High, on the basis of developmental testing, so as to represent extremes of rated complexity;
- Conformance – will also be defined as Low vs. High. Low conformance automation will be replays of a colleague's performance, specifically chosen on the basis of having used a different resolution strategy (e.g. Altitude versus heading solution). High conformance automation will be simulated through replay of the participant's own earlier performance.

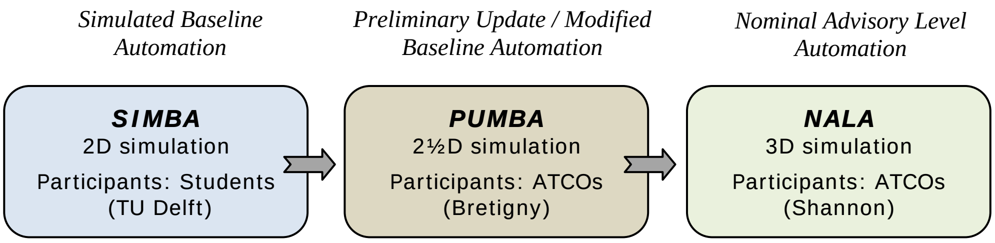


Figure 4 The MUFASA Simulation Approach.

Simulation scenarios will consist of short vignettes of approximately 2 to 3 min. each. These will be generated on the basis of developmental testing, in which continuous runs will be dissected and shorter scenarios extracted. By mirroring and rotating the scenario presentations we intend to create unrecognisable cognate pairs for eventual validation runs.

Dependent measures will focus on three separate issues: performance, workload and strategies. Performance measures will include, for example, number and type of commands issued, number of SSD inspections, minimum separation, etc. Participants will self-report both workload (using the ISA technique) and instantaneous traffic complexity. Finally, simulations plan to make extensive use of verbal protocols, in which participants talk through their performance after the fact.

VIII. DISCUSSION

The MUFASA project is currently at the point of the experimental design and HMI development. The project recognises that it is planning an ambitious series of experiments, which rely on careful scenario design and precise calibration of factor levels. For example, design will have to ensure that scenarios are repeatable but not recognisable to controllers.

The experimental protocol hinges on our being able to convince participants that they are not merely observing replays of their own previous performance (or of their colleagues). We must also create scenarios and test protocols that can scale up from university students during preliminary simulations, up through later simulations with experienced air traffic controllers. Further we will have to use developmental testing to establish complexity levels that ensure that task load is neither trivially low nor excessively high, and is set to a point at which the decision to use automation is a meaningful one.

ACRONYMS

CD&R	Conflict Detection and Resolution
CORA	Controller Resolution Assistant
ERASMUS	En Route Air Traffic Soft Management Ultimate System
ISA	Instantaneous Self Assessment
LOA	Level of Automation
NALA	Nominal Advisory Level Automation
PUMBA	Preliminary Update / Modified Baseline Automation
SIMBA	Simulated Baseline Automation
SSD	Solution Space Diagram
TC-SA	Trajectory Control by Speed Adjustment

---

[3] The design will not be fully-crossed, as the issue of conformance is only relevant under automated conditions.

REFERENCES

[1] SESAR (2007). Deliverable D3: the ATM target concept, DLM 0612 001 0200a, September 2007.

[2] Billings, C. E. (1997). Aviation Automation: The Search For A Human-Centred Approach. Hillsdale, N.J: Lawrence Erlbaum Associates.

[3] Westin, C. & Hilburn, B. (2011). Report on Initial 3D Framework. SESAR project E.02.08, MUFASA deliverable D1.

[4] ERASMUS (2009). Final report. En Route Air Traffic Soft Management Ultimate System. Deliverable WP4 - D 4.6.

[5] Merritt, S.M. & Ilgen, D.R. (2008). Not all trust is created equal: dispositional and history-based trust in human-automation interactions. Human Factors, 50(2), 194–210.

[6] Kirwan, B. and Flynn, M. (2002b). Towards a controller-based conflict resolution tool – a literature review. EUROCONTROL document ASA.01.CORA.2.DEL04-A.LIT.

[7] Schaefer, D., Flynn, M. & Skranning, G. (2003). The Presentation of Conflict Resoution Advisories to Air Traffic Controllers – A Human Factors Perspective. In D. Harris et al. [Eds.] Human-Centred Computing: Cognitive, Social and Ergonomic Aspects, 572-576.

[8] Mercado Velasco, G.A., Mulder, M., & van Paassen, M.M. (2010). *Analysis of Air Traffic Controller Workload Reduction Based on the Solution Space for the Merging Task*. Proceedings of the AIAA Guidance, Navigation, and Control Conference, Toronto, Canada.

[9] Parasuraman, R.J., Sheridan, T.B. & Wickens, C.D. (2000). A model of types and levels of human interaction with automation. IEEE Transactions on Systems, Man, and Cybernetics – Part A: Systems and Humans, 30(3), 286-297.

[10] Fuld, R. B.; Liu, Yili; Wickens, Christopher D. (1987). The Impact Of Automation On Error Detection: Some Results From A Visual Discrimination Task. Human Factors and Ergonomics Society Annual Meeting Proceedings, 31(2), 156-160.