ECOLOGICAL AUTOMATION

Air Traffic Control: Making the Invisible Visible

Clark Borst, Assistant Professor, Faculty of Aerospace Engineering, TU Delft

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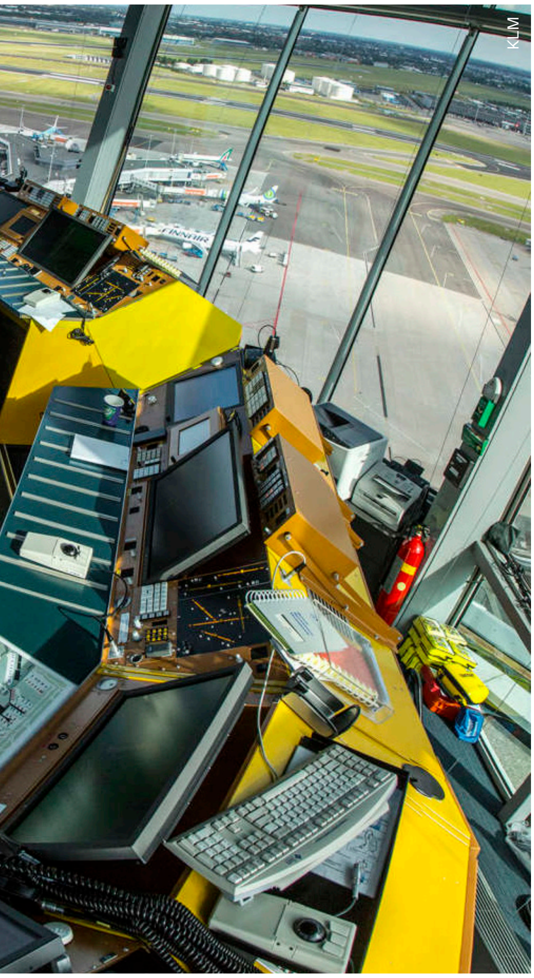
Automation often leads to a loss in situational awareness, mainly because it is designed as a 'black box' that poorly communicates its intentions and constraints. The Ecological Interface Design framework can be used to make automation more transparent for human operators.

CHALLENGES FOR FUTURE AIR TRAFFIC SYSTEMS

Predicted air traffic growth and the associated economic and environmental concerns are forcing a fundamental redesign of the air traffic management system (ATM). In Europe and in the United States, similar efforts are being undertaken to modernize the current ATM system. This redesign will focus largely on new forms of automation, requiring humans to supervise more complex and more intelligent automated systems to ensure a high performance and safety level. This however, has also given rise to a growing concern within the Air Traffic Control (ATC) community: will controllers remain competent and skilled enough to safely assume control should the automation fail? Similar to how flight deck automation and autopilots have been reported to play a role in skill erosion of commercial airline pilots [1], the fear is that smarter automation will dumb down air traffic controllers. Note that not only the ATC community is moving towards an increase in automation. This trend is visible in almost all transportation domains, most recently in the automotive industry with the undertaking of the "self-driving car". As such, these domains (eventually) all struggle with the same question: is it possible to exploit the advantages of automation whilst maintaining a competent and skilled workforce?

THE AUTOMATION PARADOX

Traditionally, automation is considered as something that replaces human activities. In the process of pushing the human out of the control loop, engineers often pay little attention to properly inform the human about what rationality is guiding the automation. This eventually makes operators lose their understanding about why, when, and how to intervene in case the machine reaches its boundaries. We are now reaching a limit of what can be automated with today's technology. Though we can make an autopilot follow a predefined flight trajectory automatically, a human still outperforms a computer in adaptive decision making and creative problem solving. This type of behaviour is of paramount importance in handling unexpected events and in dealing with uncertainties. Such abilities are occasionally seen when a human "saves the day", as in



Eurocontrol's Maastricht Upper Area Control Center manages traffic above 24,500 feet over the Benelux, Northwest Germany, and a small part of Northern France.

the Apollo 13 moon mission, or the Hudson River water landing. Thus, it seems that the more we automate, the more critical the role of the human becomes, not less. This is formally known as the 'automation paradox' and teaches us that the ultimate responsibility for the safety of operations still lies with humans. To fulfil such a critical role, people need to have a deeper understanding of the problem at hand. More automation also implies the need for more communication, not less [2]. Though what type of information supports adaptability and creativity?

ECOLOGICAL AUTOMATION: A NEW PERSPECTIVE

In processes governed by the laws of physics, creative solutions are limited. For example, an aircraft cannot sustain flight when it is flying slower than the stall speed. The turn radius of an aircraft is constrained by the maximum allowable load factor. Besides these 'internal' aircraft constraints, the maneuverability of aircraft is also affected by 'external' static and dynamic environmental (i.e., ecological) constraints such as terrain, air traffic and weather. Ecological Interface Design aims to make these work domain constraints salient on an interface in such a way that people can directly perceive the entire (physical) space of possibilities [3,4]. Here, the challenge is to find an appropriate mathematical representation that resonates better with the way humans think and solve problems. Finding such a representation also impacts the model we eventually embed in our automation. That is, instead of using representations geared toward finding single, optimized solutions, automation should provide the boundaries for actions and enable the human to decide on the course of action.

4D TRAJECTORY MANAGEMENT

The idea of underpinning ecological automation is best explained by means of an example. In the future airspace environment, aircraft are expected to be at a specific point at a specific time [5]. Such 4D trajectories will generally be planned several weeks to months before the actual flight to optimize the flux of air traffic through a piece of airspace (i.e., sector). During flight, however, unplanned disturbances may arise, such as local adverse weather. These events would require an air traffic controller to adjust the trajectories, whilst adhering to the original planned time and position at which the aircraft needs to leave the sector as much as possible. Instead of tackling this problem with advanced path-planning algorithms that optimize a certain multi-dimensional cost function to select the best possible trajectory, we have demonstrated that we can also let the human perform this task by visualizing a 'solution space' using relatively simple conflict detection algorithms. Figure 1 shows an example of such a solution space.

Here, two aircraft in conflict are highlighted in red and for the top red aircraft the solution space is visualized. The green area portrays a space of valid locations for a controller to insert intermediate waypoints. The boundary of this space depends on the maximum aircraft speed — flying a longer distance requires a higher speed to still arrive at the sector exit point at the original planned time. Of course, an intermediate waypoint can be placed outside the solution space, but this will result in a delay at the sector exit point as the aircraft cannot fly the additional track miles fast enough. The red areas mark invalid waypoint locations, because they will either not solve the current conflict or result in a new conflict with another aircraft. Thus, any intermediate waypoint inserted inside a green area is valid and will result in a con-

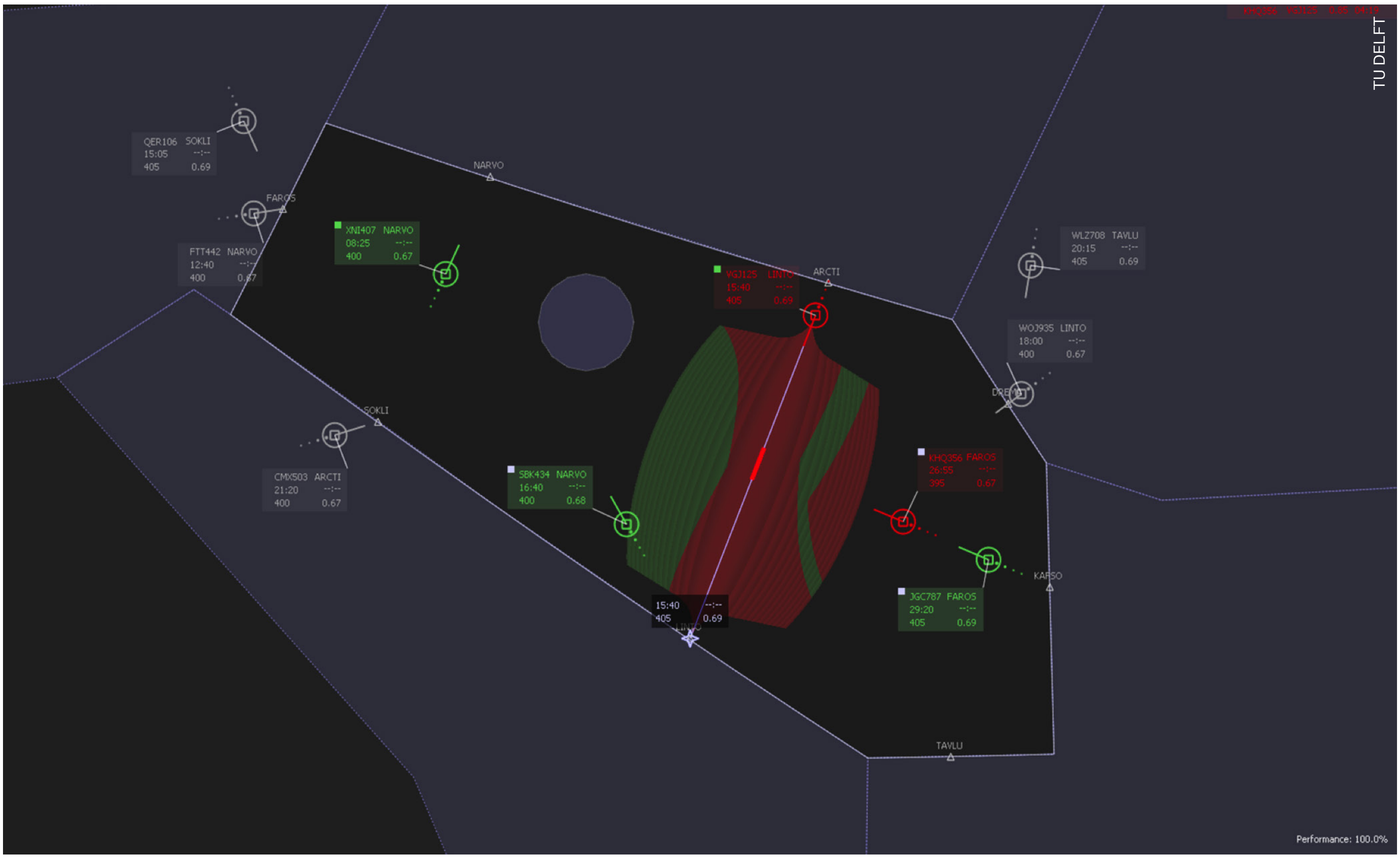


Figure 1 - Prototype of a next generation radar screen, showing a spatio-temporal solution space to solve conflicts between aircraft.

flict-free trajectory with all surrounding aircraft. From this figure, it can also be seen that putting an intermediate waypoint in the left side of the solution space is most favorable in terms of robustness, because it features the largest green area. Putting a waypoint in this area also hints at what the resulting traffic pattern will look like: the selected aircraft will pass the other aircraft in front. As such, in one glimpse a controller can spot all possible solutions that resolve the conflict and visually identify the most favorable solution area, whilst adhering to the original planned exit time.

The solution space representation is also compatible with higher levels of automation, in which the computer can analyze the solution space and make a suggestion (i.e., advisory) on where to insert an intermediate waypoint to solve the conflict. By showing the advisory inside the solution space, a controller can inspect the validity, assess the quality of the given advice and either accept or reject it. In this way, the automation constraints become directly observable (i.e., transparent) through the interface and it becomes relatively easy to manually re-direct solutions warranted by situational demands.

EMPIRICAL INSIGHTS: DOES ECOLOGICAL AUTOMATION WORK?

Several human-in-the-loop studies in simulated environments have indicated that the 'solution space' approach helps controllers in gaining insight into traffic situations (i.e., situation awareness), keeping them in the loop, and allowing them to solve problems in their own way [4,5]. Especially this last point is interesting for ATC: air traffic controllers are amongst the most critical population when it comes down to accepting new technology. In the past, several technologies have not been embraced by the ATC community, simply because controllers did not accept or appreciate them [6]. In many cases, their judgment was fair because the technology would force them to work along a fixed set of strategies and procedures. Although this can reduce the complexity of their work, procedural compliance is often too restrictive in highly dynamic environments featuring uncertainties.

Despite the benefits ecological automation has to offer in terms of human-machine interaction, there is also a cost associated with it. Since operators are free to choose any strategy they prefer, given it does not violate work domain constraints, they can also choose suboptimal strategies. Current developments in modernizing the air traffic management system are, however, largely focused on "optimization", e.g., optimal landing sequences, optimal fuel usage, and optimized flight trajectories. When ecological technology will be used, the focus will shift from optimal control to robust control, sacrificing optimality relative to any situation. However, for complex work where system dynamics or values associated with competing goals can change in unpredictable ways, robust solutions will generally be preferred to solutions that are optimal most of the time, but they can fail catastrophically in a small set of situations. As long as our machines are not smart enough, technology should leverage people's abilities, and not replace them. ✈

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