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Increasing trust in optimization based ATM systems through training

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Abstract

Air Traffic Management is the complex task of safely managing the flow of aircrafts. This task needs to be solved efficiently to avoid hindering the growth of the aviation sector. Optimization-based decision support tools could assist but, this being a safety-critical and conservative domain, a high level of trust needs to be in place. The amount of trust depends on the level of automation and familiarity with the tools. We argue that this needed trust could best be built if optimization based tools are used in the training of air traffic controllers. We discuss how this training can help air traffic controllers and the model of optimization.

Introduction

Air Traffic Management (ATM) involves organizing and controlling the flow of traffic on the ground and in the airspace around the airport in a safe and efficient manner. The growing number of flights puts increasing pressure on existing ATM system, which is already approaching its limits. Incremental improvements in how air transport is managed will not be sufficient. Large improvements are required or ATM will become a bottleneck for the sustainable growth of the aviation sector, which will lead to more and more passenger delays, increased costs, and pollution (EU, 2001). To tackle this, EU initiated a large long-term public-private partnership called SESAR (SESAR, 2015)—a €2.1 billion undertaking to conduct a complete overhaul of European airspace and its ATM system. The United States have launched a similar initiative, called NextGen (NextGen, 2015).

Optimal or very efficient resource utilization within ATM requires new automation tools based on mathematical optimization. In our previous work, we proposed a training tool based on visualization along with discrete optimization models and algorithms, and argued that it would improve air traffic controller (ATCO) training (Karahasanovic *et al.*, 2015). This paper argues that the use of optimization in training would assist in refining the optimization model, which in turn will build more trust in it. The more accurate the model, the better suggestions it will provide and thus the more it will be trusted.

The paper is organized as follows: Section 2 provides a brief background in ATM optimization, visualisation, automation, and the problem of trust. Section 3 presents our arguments on how optimization through learning can build the trust needed to use optimization operations for ATCO. We conclude in Section 4.

Background

Optimization in ATM

There is a large need for optimization-based decision support tools in the aviation domain (Burke *et al.*, 2010; Lan *et al.*, 2006; Rosenberger J *et al.*, 2004). Airline companies have largely been successful in adopting optimization-based tools to assist in establishing aircraft schedules, crew schedules and price-setting policies, so as to maximize airline profitability. In contrast to airlines, air traffic management (ATM), which organizes and expedites the flow of traffic on the ground and in airspace, lacks optimization-based decision support tools. ATM's scheduling, sequencing and routing tasks are combinatorial explosive problems, very unsuitable for manual solution (the number of possible plans to evaluate increases exponentially with the size of the problem). In other domains like road and maritime transportation, optimization techniques are used to tackle the same problems with great success. To handle this complexity manually, air traffic controllers decompose their problem into smaller parts and give individual controllers responsibility for one part of the original overall problem. However, this compartmentalization approach has a large downside—it disregards the larger picture and, most likely, some globally efficient solutions are removed from the investigated solution space. In addition, a good decision for one ATM area might create havoc for the neighbouring area.

The research literature on the optimization problem in the ATM domain is quite wide. Interestingly, researchers have largely continued with the compartmentalization approach (albeit in fewer parts). The optimization literature considers three distinct ATM problems: The Arrival Management Problem (AMAN), the Surface Management Problem (SMAN) and the Departure Management Problem (DMAN) (Atkin, 2008; Bennell *et al*., 2011). Recent optimization research has managed to integrate AMAN, SMAN and DMAN and to solve them as one problem (Kjenstad, 2013). Note that this problem decomposition is a general issue for the optimization community (Nordlander *et al*., 2013). In some cases, decomposition is the only way, considering the complexity of the problem, the maturity of the algorithm, and available computation power. Still, given the downside explained above, we should aim to avoid it as much as possible. Even though ATM faces very complex combinatorial problems and optimization research exists on those problems, almost no optimization-based decision support is used by air traffic controllers. We have had a hard time finding any relevant research on how optimization assist planners during their training. The AI community has conducted a lot of research on model refinement through knowledge elicitation techniques (Burge, 1996). Furthermore, some relevant work in optimization model refinement through user interaction also exists, that could be useful for us (Nordlander *et al*., 2007).

Human Computer Interaction in ATM

The field of Human Computer Interaction has been traditionally "concerned with the design, evaluation, and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them"(SIGCHI, 2015). It is a multidisciplinary field that lies at the intersection between the social and behavioural sciences on the one hand, and computer and information technology on the other (Carroll, 2003). Closely related to this is the field of Interaction Design, which is concerned with "designing interactive products to support the way people communicate and interact in their everyday and working lives" (Rogers *et al*., 2011). Design of automation based systems and understanding of their use is gaining more and more attention with the increased usage of such systems.

Automation has been defined as any action, either manual or cognitive, that can be performed by humans but is performed by machines, including information processing, decision making and controlling actions (Moray *et al*., 2000). The following types of tasks that can be automated have been identified: monitoring or taking information, generating options or strategies for achieving goals, selecting or deciding what option to employ, and implementing or carrying out actions (Endsley & Jones, 2004) These tasks can be performed by humans, computers or humans and computers together. Automation can vary from no automation to complete automation.

In many domains such as operating power plants, ATM, medical systems, or commanding rescue operations we need technology to help us efficiently process a large amount of information and gain a high level of understanding of what is happening –systems designed to support *situation awareness*. Endsley and Jones define situation awareness as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future". They define the following three levels of situation awareness:

- Level 1—perception of the elements in the environment
- Level 2—comprehension of the current situation
- Level 3—projection of future status

While introducing automation in highly complex environments might reduce the workload of the operators, it might also reduce the operator's situation awareness and lead to the *out-of-the-loop-syndrome* (Endsley & Jones, 2004) If the automation fails or encounters conditions which it is not programmed to handle, the operator is not able to react properly due to reduced situation awareness.

Introducing automation in ATM systems has been met with scepticism by controllers for several reasons. Automation might increase workload instead of decreasing it, due to requirements for additional data entry; it may impinge on their traditional functions or create uncertainty about legal responsibilities (Benel, 1998). However, trusting the system to perform correctly and understanding how it works is the first prerequisite of system acceptance.

Optimization and Human Computer Interaction

The exiting interdisciplinary literature is sparse and one-sided, to a large extent focusing on using optimization to assist in interface design, keyboard layout etc. The long overdue "Workshop on Principles, Techniques and Perspectives on Optimization and human computer interaction (HCI)" will take place this summer within a large HCI conference (Kristensson Per Ola *et al*., 2015). Research has also examined how visualization techniques can support the teaching and learning of optimization algorithms (Jones & Scaife, 2000). The results indicate the usefulness of such tools. We believe that optimization and HCI could greatly benefit from each other.

Learning to increase ATM trust in optimization

Unfortunately, ATM is a very conservative and safety critical domain in which a high-level of trust needs to be achieved before implementing and using any new tools. Moreover, the curve for gaining trust is quite steep, making it hard to introduce novel prototypes. As mathematical optimization is often seen as a black box, it creates additional trust concerns. Consequently, air traffic controllers need optimization techniques to efficiently tackle their growing workload but have difficulties in gaining sufficient trust to use it. The amount of trust needed is also dependent on the level of automation involved. The relationship between humans and automation can vary from no automation on one side (humans do the whole job), through partial automation (humans do the job with the help of computers) to complete automation on the other side (computers decide everything ignoring human input) (Moray *et al*., 2000). The trust relationship between humans and computers is influenced by the level of automation, system familiarity, and system complexity. The trustworthiness of a system will increase over the time if the system behaves correctly. Our approach is to get decision support systems based on optimization techniques into ATM operations through air traffic controller (ATCO) training.

At the same time, it is not only ATM operations that need drastic changes, but also ATCO training (Voller & Fowler, 1998). ATCO training sessions are less critical than operations, and thus there is more openness to trying new tools. The level of trust needed is lower and the trusting curve is less steep. We believe that introducing optimization in training would have the following benefits:

- it would improve training
- it would assist in refining the optimization model
- it would help building trust in the optimization

In combinatorial complex environments like ATM, finding optimal solutions/decisions manually is very unlikely. As the many possible decisions and objectives should be considered simultaneously, mathematical optimization excels. In previous projects we have worked with visualisation for ATCO training, and controllers have highlighted that they would like to see optimal solutions or suggestions for improvement, to discuss them in relation to their manual solutions (Eide *et al*., 2014). Use of an optimization-based tool for training might help refining the model (so it would be more accurate for real use)—controllers will identify shortcomings in the tool's solutions that will allow us to build a more accurate model. As the model is constantly refined it will provide better suggestions and this will build trust. With familiarity and trust in place, the introduction of optimization-based decision support for ATM operations is facilitated.

Conclusion and future work

Air Traffic Management (ATM) is a very conservative and safety critical domain where substantial trust needs to be in place before implementing and using any tools. The fact that mathematical optimization is often seen, by non-optimization experts, as a black box makes it even harder for air traffic controllers to adopt such tools. The amount of trust needed is also dependent on the level of automation used. Our approach to get decision support systems based on optimization techniques into ATM operations goes through Air Traffic Controller (ATCO) training. We will continue looking into how the interdisciplinary domain between HCI and optimization as well as the AI community research on elicitation techniques. We believe this can help us in increasing trust in optimization based ATM systems through training

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