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FLIGHT ALLOCATION IN SHARED HUMAN-AUTOMATION EN-ROUTE AIR TRAFFIC CONTROL

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Allocation is a challenge for higher levels of automation in air traffic control, where flights can be dynamically assigned to either a human or an automated agent. Through an exploratory experiment with six professional air traffic controllers, insight was gained into the possibilities and challenges of human-automation teamwork in an en-route environment. Participants showed high levels of automation trust, but mostly ignored automation-suggested allocations, preferring a highly automated sector instead. Most flights were delegated to automation, after they were given a direct and conflict-free path. Flights handled manually were those requiring level changes or non-standard routing. Future research should focus on establishing specifically which flights can be automated.

Air traffic controllers (ATCOs) work in a challenging and demanding environment. The continuous quest for more efficient and safer air travel, drives the development of more advanced automation. Both Europe and the United States aim for higher levels of automation in the coming decades with a more supervisory/strategic role for humans (Prevot, Homola, Martin, Mercer, and Cabrall (2012); SESAR Joint Undertaking (2019)). In such an environment, less people can handle more traffic in larger sectors. Despite high levels of automation, humans are expected to play an important role in supervising these future systems and to intervene when automation falls short (Metzger and Parasuraman (2005)); people will ultimately remain responsible.

To be able to intervene, it is essential that ATCOs maintain vigilance, situation awareness and a sufficient skill level to perform tasks manually (Bainbridge (1983)). This could be achieved by not making the human a supervising bystander, but have him/her work side-by-side with automation in a team, both able to perform and share tasks. This sparks the question of what such co-operation should look like, and what impact it will have on human-automation performance.

Currently, airspace is divided into sectors, each under the responsibility of a different ATCO. This requires considerable coordination between adjacent sectors and may lead to an imbalance in traffic load (and thus workload). To mitigate these issues, Birkmeier, Tittel, and Korn (2016), among others, considered so-called flight centric or sectorless operations. Instead of coupling controllers to geographic areas, a single controller would be assigned to several flights, from departure to arrival, reducing the number of handoffs and possibly providing a better workload balance. This, however, also introduces new challenges. Consider, for example, when two flights under control by different ATCOs are in conflict. Who should then solve the conflict?

What if that other controller is not another human, but an automated system? How are flights then assigned to either a controller or automation? Should all aircraft involved in a conflict be controlled by either the ATCO or the automation, so as to mitigate additional workload related to coordination? If not, who solves a conflict? In addition, with an automated agent, it becomes possible to share (sub)tasks dynamically, back and forth, between human and automation. This could establish true teamwork, but only if above-mentioned questions have been answered first.

This paper discusses an exploratory experiment on the allocation of flights in a shared human-automation en-route airspace. Control over which flights were automated was given to the ATCOs themselves, although initial automation-based suggestions were given for each flight.

Method

Participants and Apparatus

Six professional ATCOs (age M = 38.3, SD = 10.0, years of experience M = 14.8, SD = 8.7), from Maastricht Upper Area Control (MUAC) participated in a real-time simulator experiment. A TU Delft-built Java-based simulator (Fig. 1) was designed to mimic the MUAC interface, to ensure that participants could focus on working with the experimental automation. A 1920 x 1920 pixels 27" display was used with a standard computer mouse for control inputs.

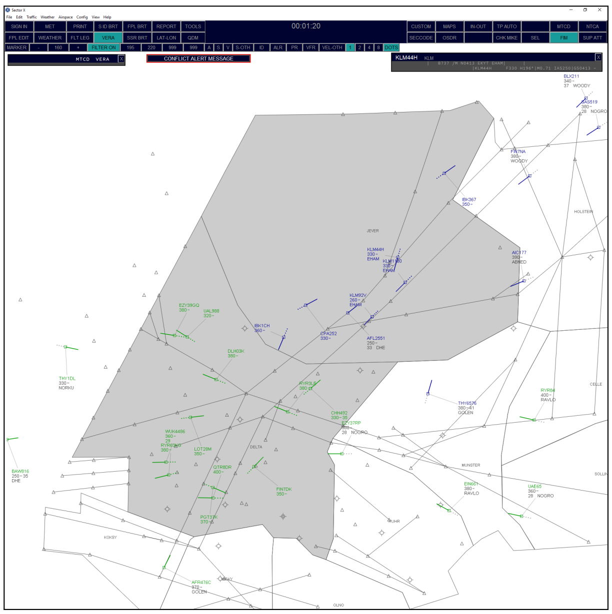

Figure 1. Simulator interface, with blue aircraft allocated to automation and green aircraft to the human ATCO. Background colors have been inverted here for clarity.

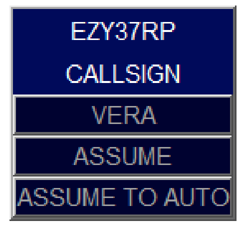

Figure 2. Callsign menu, as shown when clicking the callsign in an aircraft label. The ATCO could delegate a flight to automation by pressing "ASSUME TO AUTO". Once the flight was assumed, a "TRANSFER" button was added to the menu.

Airspace and Traffic Scenario

Participants were responsible for traffic above FL245 in the combined DELTA and JEVER sectors, above the Netherlands and part of Germany. Each ATCO experienced the same traffic scenario, resembling an average day in February 2020 (prior to the COVID-19 pandemic). There were between 15 and 30 flights in the sector at any time (M = 21, SD = 4). Flights followed standard routing or directs to their designated exit points. Besides overflying traffic, arrivals and departures to several airports, within or close to the sector, were included. There was no wind.

Automation

During the exercise, the ATCOs were accompanied by an automated “colleague". When flights entered their sector, the ATCOs had to decide whether to manually assume the flight or delegate it to automation (Fig. 2). This allocation remained flexible, such that they could re-assume manual control or delegate flights to automation at any time, anywhere in the sector. All flights had to be manually transferred to the next sector, including those delegated to automation. Automation was capable of performing the following tasks:

- Ensure sufficient separation between automated aircraft (5 NM, 1000 ft),
- Deliver aircraft at their exit point and transfer level, descending as late as possible, and
- Descend arrivals to FL260 to be transferred to lower area control.

When two automated aircraft encountered a conflict, it was always solved in the vertical plane. Automation would never issue any heading commands or direct-to's. In case of a human-automation conflict, it was up to the ATCO to solve it, under the presumption that automation would not know the ATCO's intents. Apart from showing the clearances in the aircraft labels, automation did not provide any feedback on its intentions.

Procedure

After signing a consent form, each participant received a ten-minute training, during which the automation was introduced and participants familiarized themselves with the interface. Both a human-automation and automation-automation conflict were shown to demonstrate how automation would handle both situations. The training was concluded with a short questionnaire.

Next, the measurement run started with a five-minute take-over period, during which no commands could be issued, followed by 90 minutes of real-time simulation. Each ATCO was subjected to one allocation suggestion scheme (Table 1), based on flight type or entry sector. The suggestions were shown by the label color upon sector entry (green = manual, blue = automated), but the ATCOs were not told which scheme was applied to them. In all cases, they could ignore the suggestions and re-allocate each flight at any time, even after delegating it to automation.

Throughout the run, an observer asked the ATCOs to explain their actions and what they were taking into consideration. Every three minutes, the ATCOs rated their instantaneous workload by clicking on an on-screen 0-100 scale. After the experiment, they completed an extensive questionnaire, followed by a radar replay allowing specific situations to be reviewed.

Table 1. *Suggested human-automation flight allocation strategies.*

ATCO	Basic traffic	Complex traffic	DELTA	JEVER
1	Human	Automation	-	-
2	Automation	Human	-	-
3	-	-	Human	Automation
4	-	-	Automation	Human
5	Human	Human	Human	Human
6	Automation	Automation	Automation	Automation

Note. Basic traffic has to descend/climb 2000ft or less in the sector. All other traffic is labelled as complex.

Results and Discussion

Allocation Strategies

All ATCOs delegated at least 50% and up to 100% of traffic to automation, regardless of the suggested allocation (Fig. 3). Whereas most ATCOs largely ignored the suggested allocation, ATCO-3 tried to follow it when he realized that one of the sectors was completely handled by automation. He even delegated/assumed flights as they crossed the border between the two sectors, commenting that solitary manual flights in a predominantly automated area were difficult to handle. The big drop in automation observed for ATCO-4 around 50 minutes, was caused by him purposely re-directing flights manually to "test automation" with a more complex scenario. He stated that he would have been okay with purely monitoring a completely automated scenario.

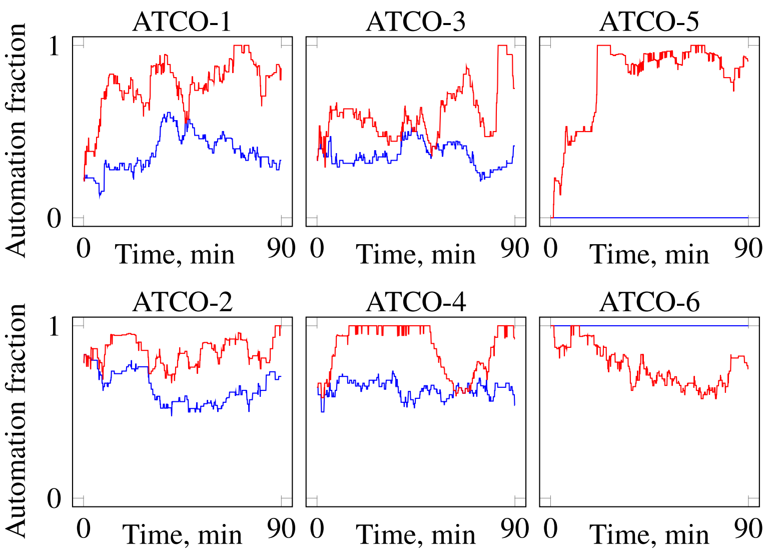

Figure 3. Time traces of the fraction of flights allocated to automation (red). The blue line shows the fraction, if the ATCOs would have followed the suggested allocation on airspace entry (see Table 1).

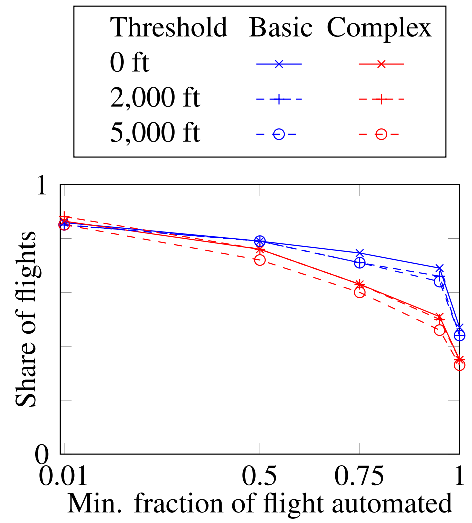

Figure 4. Cumulative share of flights that was delegated to automation for a minimum fraction of their duration, as a function of level change threshold.

When asked about all allocation strategies from Table 1, the ATCOs unanimously agreed that complex flights, here defined as requiring more than 2,000 ft level change, need to be handled manually (potentially with support tools). They indicated a strong preference for delegating basic flights to automation, which is for most ATCOs also reflected in the time that they delegate such flights to automation (Fig. 4). Although some ATCOs said 5,000 ft would have been a more appropriate choice of level change threshold, at which traffic was divided in basic and complex, this is not directly reflected in the figure. All traffic that had to change levels has evoked more manual control than overflights with zero level change and could thus be considered "complex".

Apart from this division into basic and complex traffic, the questionnaire provided more insight into how ATCOs determined whether flights should be delegated or not (Fig. 5). Traffic directly around the flight was especially important when there were many manual flights and delegating a single flight to automation would have added (too) much uncertainty. The suggested allocation was given low priority, or ignored by most ATCOs (except ATCO-3), as confirmed by Fig. 3. In general, flights were assumed manually, sent on a direct to their exit point and only delegated to automation when clear of conflicts, irrespective of the suggested allocation. If automation would have been capable of giving directs, the ATCOs would have delegated more flights.

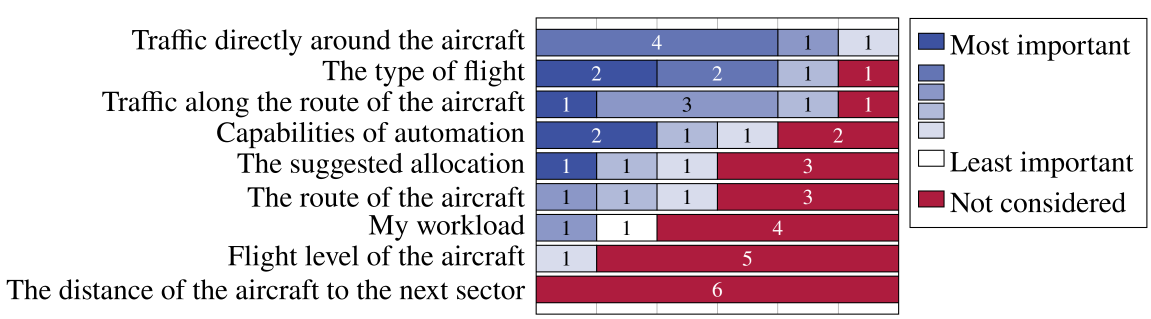

Figure 5. Driving factors that made ATCOs decide to delegate flights to automation, or not.

Trust in Automation

At the start of the experiment, all ATCOs reported to have a high level of trust in automation in general (Fig. 6). Nonetheless, they were suspicious of the experimental automation after the (short) training. Throughout the 90-minute run their trust increased considerably, according to the ATCOs mainly due to seeing the automation perform well. The rule-based form of automation (programmed to be "perfect"), clear separation of responsibilities and absence of uncertainties, such as wind and pilot behaviour, further contributed to this. ATCOs did, however, not like the lack of feedback, a common pitfall in automation design hindering the establishment of human-automation teamwork (Norman (1990)). As automation did not indicate where or when it would descend aircraft, ATCOs sometimes assumed aircraft manually, solely to prevent them from descending unexpectedly. All ATCOs would have liked automation to at least show its intentions about where on the trajectory it would start and end a climb or descent.

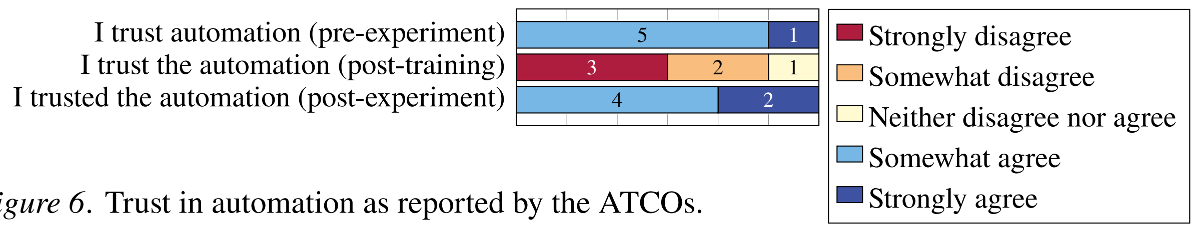

Figure 6. Trust in automation as reported by the ATCOs.

Task Allocation

While this experiment focused on aircraft allocation, a human-automation team may also be created by sharing tasks. Four out of six ATCOs included the capabilities of automation in their allocation strategy (Fig. 5). We replicated part of the study from Prevot et al. (2012), to see what kind of tasks the ATCOs would like to do themselves, share with automation or completely delegate to automation. In line with the findings of Prevet et al., the ATCOs indicated that a considerable number of tasks can be either shared with or completely delegated to automation (Fig. 7). Transfer of control can be automated as a first step towards more automation, but ATCOs should be able to reject auto-transfers as well as to initiate early transfers. The ATCOs prefer to keep short-term, tactical actions manual, while more strategic long-term planning and routine tasks can be (partially) delegated to automation. Presumably this is because automation can introduce too much uncertainty in critical short-term situations.

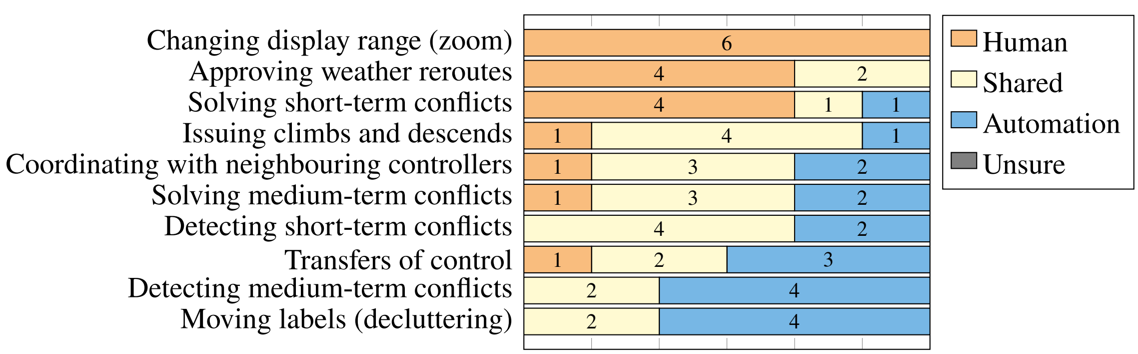

Figure 7. Allocation of tasks between human and automation as desired by the ATCOs.

Situation Awareness

All ATCOs classified their situation awareness as “okay”, the middle score on a five-point Likert scale from “poor” to “very good”. Several mentioned that they paid less attention to the blue automated aircraft, akin to transferred flights, even though they were still responsible for these flights. At the only (not explicitly programmed) occurrence of a human-automation conflict in the experiment, the involved ATCO was surprised by the short-term collision alert and explained that he had not seen the automated aircraft as it was emerging from, in his words, “a sea of blue aircraft”. Future experiments with eye trackers could give insight in changing scanning patterns when aircraft are delegated.

Conclusion

This exploratory study gained useful insights into human-automation teaming in a realistic ATC setting. We showed that professional en-route ATCOs are not averse to sharing their work in a sector with automation. In a simplified situation, lacking uncertainties by wind, emergencies and pilot requests, a high level of delegation to automation was reached, under the condition that flights were on direct routes and free of conflicts. ATCOs generally ignored the suggested allocation, suggesting a need for a different allocation scheme that may be more accepted.

Future research should take a closer look at determining specifically which flights should be considered “basic” or “complex”, such that a fitting allocation scheme can be applied. Additionally, the influence of environmental uncertainty (e.g., wind and pilot delays) and automation capabilities should be researched. Together with empirical studies on the various forms of task sharing and distribution, this can help establish human-automation teamwork in a shared ATC environment.

Acknowledgements

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