Importance of Delegation and Redelegation in Human-Autonomy-Teamed Air Traffic Control

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Abstract. Across almost all European air navigation service providers there is a current shortage of air traffic controllers (ATCOs), which contributes significantly to delayed or cancelled flights. This reduces the cost efficiency, increases the environmental impact of air traffic and causes inconvenience to airlines and passengers. Looking at the opportunities the widely discussed new generation of artificial intelligence offers to air traffic control one researched solution is the introduction of a digital (artificial intelligence) air traffic controller. It can be expected that the first operational use of a digital ATCO will not be allowed nor able to take over air traffic tasks of ATCOs to their full extent. A researched (interim) solution is a (human autonomy) team build by ATCO(s) and digital ATCO to handle air traffic together in parallel within the same airspace. In this setup, situations can develop that digital ATCO is not (yet) able to handle or where ATCO likes to change allocation as she will stay responsible for safe air traffic control. This requirement for a bi-direction change of authority (i.e. transfer of control) is termed delegation and redelegation in this poster. A first demonstrator of a functional delegation and redelegation process and its implementation was presented to seven ATCOs in a workshop and tested by them using short scenarios to clarify questions about the user interface and user experience. The results showed UEQ's Pragmatic Quality scores of above 1.4 proving the user-friendliness of the delegation process.

Keywords: Digital Controller · Human Autonomy Teaming · Future Air Traffic Control

1 Introduction

The air traffic management system in Europe faces a significant challenge: with recovering and predicted further growing traffic levels [5] the shortfalls in en-route capacity reached the worst level since 20 years in 2023 [6]. The resulting

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delays can be assigned to weather, capacity, air traffic control (ATC) disruption and ATC staffing in the order given. However, the latter plays a role in 80% of the cases assigned to capacity and disruption as well. This makes ATC staffing the primary factor for air traffic flow management (ATFM) delays; in 2023 contributing to the total en-route ATFM delay of 18.1 million min [6]. Thus, aircraft flying over Europe were unnecessarily airborne for over 300,000 h causing pollution and inconvenience to passengers. Based on a rough calculation for an A320neo (as one of the most common types of aircraft) with 165 seats and a fuel burn of 0.01758 kg/km/seat [11] and a cruising speed of 450 kn [4] this equals more than 2.28 M kg CO_2. Addressing these issues by researching and implementing higher levels of automation, i.e. introduction of a digital ATCO (D-ATCO) raises followup challenges. Firstly, research has shown that pure automation of ATC while leaving the responsibility to human (supervising) will cause decrease of situational awareness and ATCO skills [3,13] making an effective supervision unrealistic. Secondly, a full automation of ATC is an costly (time, effort, money) undertaking, not to be expected to be implemented in the short term. However, focusing on intermediate steps, this again reinforces the first point. This is where human-autonomy-teaming (HAT) research comes in, enabling an earlier implementation, relieving human (or solving staff shortages and enabling the processing of the demand) and giving possibility to keep ATCO skills and situation awareness high enough to take over [7,17]. In turn questions needs to be answered regarding the parallel work of human and D-ATCO in one airspace. [14] mentions here for example:

- Which flights are allocated to whom and considering what aspects?
- Who is responsible for a conflict between aircraft under ATCO and D-ATCO control?

Whatever the answer is, a possibility for delegation is crucial. While these researches focusing on different aspects of human-autonomy-teaming and addressing them, they always assume a possibility for human to delegate, i.e. give control to or take control back from D-ATCO. They lack a concrete investigate of how this should be conventionalized and implemented. Furthermore, it is limited to the ATCO being actively requesting control back or allocating control to D-ATCO. [14] found that ATCOs will use individual strategies for allocation preventing the effective implementation of general allocation rules. Additionally, this ATCO-driven allocation will cause additional workload; ATCOs in [1] noted and liked to be relived from. However, they still favoured to keep the opportunity to change the allocation. This poster presents related work in Sect. 2 regarding research in digital ATCO in general and human-autonomy-teaming in ATC in particular. This includes previous workshops together with ATCOs as well as presentation of D-ATCO demonstrator system. Section 3 presents the workshop, of which the study and evaluation of the delegation discussed here formed a part. The used metrics and techniques are described. Subsequent to the presentation of results in Sect. 4, they are discussed in Sect. 5.

2 Related Work

A Digital ATCO as an concept for artificial-intelligence-based automation support in ATC was for example drafted by [8] and developed as prototype by [10] in the frame of German Aerospace Centre (DLR)'s LOKI project [2]. Previous Workshops identified ATCO's expectations, most relevant task for human autonomy teaming (HAT) and situations and issues to focus on; including delegation. In conclusion, tasks (or flights) that can be described as simple are delegated to D-ATCO [1]. However, in the dynamic ATC environment a task or flight might become non-simple with changing surrounding conditions.

The Automation Strategy of EURONCOTROL Maastricht Upper Area Control Centre foresees the same workshare between human ATCO and D-ATCO: basic and routine ATCO tasks and traffic allocated to a digital ATCO (named ARGOS), whereas complex scenarios will be handled by ATCO with D-ATCO support. ARGOS is at an early implementation stage in a constrained environment. However, the strategy foresees the possibility for ATCO to take back control [9].

These two example show that not just flight allocation is a crucial part in HAT ATC-environment [15], but especially the possibility to change this initial allocation.

3 Method

This Chapter defines the term delegation as used in this poster before the workshop setup and used metrics are described which were used to verify the delegation (between ATCO and D-ATCO) concept and prototype-implementation for an future HAT ATC environment through ATCO feedback.

3.1 Definitions

Delegation is used e.g. by [15] as a term to describe that human ATCO has currently flights allocated to a D-ATCO. This sets the focus not on the process of delegating, but rather on the status of an flight being under human or D-ATCO control. In contrast delegation (and redelegation) is used as an umbrella term to describe any transfer of control process between ATCO and D-ATCO throughout this poster. However, it is important to define sub-terms dependent on who is acting or reacting and who is sending or receiving an aircraft as the four possible combinations (modalities; capitalised) differ in importance, impact and thus in proposed implementation. The definitions are shown in Table 1.

3.2 Workshop Setup

As followup of the previous two workshops (see Sect. 2) a two-day workshop was conducted in autumn 2024 in Langen, Germany with operational ATCOs. First of all, the workshop was used to introduce the team and participants, the

Table 1. Delegation modalities

Name	Role initiating the transfer	Role receiving the aircraft	Clarifications
Delegation	ATCO	D-ATCO	disabled, if D-ATCO is not able or allowed to handle aircraft
Cancel Delegation	ATCO	ATCO	immediately transferred
Redelegation	D-ATCO	ATCO	time critical; cause information
Request Delegation	D-ATCO	D-ATCO	affirmation leading to Delegation

Fig. 1. Delegation, Redelagation (due to received coordination) and Cancel Delegation Implementation

project and the D-ATCO prototype. Thereafter, participating ATCOs were split in three groups to assess three D-ATCO dedicated functionalities in one hour sessions each. However, this poster is limited to ATCO feedback to concept and implementation of delegation. Within each session three scenarios were shown to each group, which consisted of two or three ATCOs. One of the ATCOs actively handled the system, whereas the other(s) act as bystanders, but they can discuss together. Each scenario focused on one of the modalities Delegation, Redelegation and Request Delegation (see Fig. 1), with Cancel Delegation possible in every one, but explicitly addressed in the Request Delegation scenario. All scenarios were designed for five minutes, however they were able to run longer. The scenarios were shown through a radar display simulation tool imitating DFS's operational iCAS-System. Whereas the radar display was fully functional, neither the D-ATCO nor the allocation process was, as the sessions exclusively focused on the delegation process. Instead aircraft were allocated during scenario design to create best possibilities to test the delegation modality in focus. After each scenario a multiple-choice questionnaire with tailored questions and UEQ-S was answered by the ATCOs, followed by a semi-structured interview. However, depending on time left due to queries and technical issues the discussion length and addressed items of this interview varied between groups.

3.3 Materials

User Experience Questionnaire Short Version (UEQ-S). During the evaluation workshop we assed the user experience using the User Experience Questionnaire - Short Version (UEQ-S) [16], a validated instrument designed for rapid evaluation of interactive systems. The UEQ-S consists of eight bipolar items, each rated on a 7-point Likert scale (1 = very negative, 7 = very

positive). The questionnaire measures two dimensions: Pragmatic Quality (PQ): Evaluates usability, efficiency, and clarity. Hedonic Quality (HQ): Assesses the system's attractiveness and emotional appeal. The rationale for applying the UEQ-S was its efficiency in capturing user experience while maintaining reliability and validity comparable to the complete User Experience Questionnaire (UEQ) [12].

Self-Administered Questionnaires on User Feedback. The study utilized a structured, self-administered questionnaire to assess participants' preferences, perceptions, and usability ratings regarding task Delegation, Redelegation, Cancel Delegation, and Request Delegation when using described prototype. The questionnaire comprised multiple-choice questions, ranking tasks, and Likert-scale ratings. The Delegation questionnaire asked participants first chose their preferred method for delegation function implementation, weighing the risk of unintended delegations. Options included a single click, click and hold, double click or a confirmation pop-up. They also indicated their preference for task delegation instead of aircraft delegation, selecting between individual aircraft assignments, specific tasks for all aircraft in their area of responsibility (AOR), undecided/additional to aircraft delegation, or no task delegation. For observing Delegation completion, participants selected from multiple options for feedback, such as changes in the head symbol, highlighting, additional symbols, hiding label information, or modifications to label color or style. They specified conditions for using Delegation, including routine tasks D-ATCO is qualified for, after resolving conflicts for aircraft that requires no further interaction, following answered pilot requests, in cases of personal workload overload, or never. The Redelegation questionnaire evaluated participants' views on task reassignment in ATC. They indicated if a radio check was needed post Redelegation and ranked various aircraft scenarios by priority (sequence of redelegations), including conflicts and pilot requests. Participants also specified situations where the system (D-ATCO) should redelegate control automatically. The Cancel Delegation questionnaire evaluated participants' needs for information and feedback when canceling a delegated task. Participants indicated if they needed information for cancellation and expressed preferences for observing the cancellation process through various options as already described and used for Delegation questionnaire. Finally, they were asked if a radio check should be performed after canceling the delegation, with options for yes, undecided, or no. The Request Delegation questionnaire evaluated participants' expectations on when the D-ATCO system should initiate a Request Delegation. Participants indicated conditions for Request Delegation, such as always when capable, only in specific situations (e.g., conflicts with aircraft with shared allocation), to balance workloads, to limit human operator workload, or never.

Analysis Procedure. The UEQ-S data were analyzed descriptively to summarize the user experience ratings. We recorded negatively worded items so that higher values consistently indicate a more positive user experience. Mean scores

were calculated separately for PQ and HQ, and an overall UEQ-S score was computed as the mean of all eight items. Additionally, standard deviations, minimum and maximum values, and 95% confidence intervals were reported for each subscale. The analysis was performed using an Excel Sheet reporting on descriptives, scale consistancy and inconsistance and benchmarks. The self administered questionnaires were analyzed descriptively in Excel.

Focus Group Discussion. The audio data was obtained from a recorded discussion involving ATCOs on the delegation prototype. The recording captured natural, unscripted dialogue where ATCOs provided feedback on the system's usability, benefits, and potential challenges. To facilitate qualitative analysis, the audio data was transcribed into text. This step ensures that spoken content is documented in a written format, making it easier to extract relevant insights. The Otter.ai Transcription tool was used to convert the audio into text, with attention paid to accurately capturing key statements, interruptions, and emphasis. The analysis of the audio data from the qualitative interviews followed a pragmatic qualitative approach, focusing on the extraction of key insights relevant to the evaluation of the delegation prototype. Rather than conducting a full thematic analysis or grounded theory approach, we employed a content reduction strategy to identify and summarize the most salient points from the transcript. This method aligns with qualitative content analysis and rapid assessment techniques, where the goal is to efficiently distill meaningful feedback without an exhaustive coding process.

4 Results

4.1 User Experience Questionnaire Short Version (UEQ-S)

The results from the UEQ-S indicate an overall positive user experience across both PQ and HQ dimensions, with some variation between items. PQ, which reflects the system's usability and efficiency, received consistently positive ratings. All four items in this category scored above 1.4, with the highest ratings for *obstructive - supportive* ($M = 1.9$, $SD = 0.4$) and *complicated - easy* ($M = 1.9$, $SD = 0.4$). These results suggest that participants found the system supportive and easy to use. The lowest score within this dimension was for *inefficient - efficient* ($M = 1.4$, $SD = 1.0$), which, while still positive, indicates some variation in perceived efficiency among participants. The results showed more variation in HQ, which measures the system's aesthetic appeal and innovativeness. Two items-*not interesting - interesting* ($M = 1.7$, $SD = 1.1$) and *usual - leading edge* ($M = 1.6$, $SD = 1.0$)-received positive evaluations, suggesting that users generally found the system engaging and novel. However, the items *boring - exciting* ($M = 0.7$, $SD = 1.0$) and *conventional - inventive* ($M = 0.6$, $SD = 0.8$) fell within the neutral range (values between -0.8 and 0.8), indicating that participants did not strongly perceive the system as particularly exciting or original. Results suggest that the system is functional and enjoyable but it

does not firmly stand out in terms of innovation or excitement. Based on the UEQ-S interpretation framework [16], scores above 0.8 are considered positive, meaning the system was well-received. Given our results, the PQ dimension was uniformly positive. Users thus perceived the system as efficient, easy to use, and supportive. The HQ dimension also received positive feedback, but two items remained neutral, indicating room for improvement in making the system more engaging and innovative.

4.2 User Feedback Delegation

Delegation Function Preferences. Participants indicated their preferred method for initiating Delegation. The majority ($n = 4$, 57.1%) preferred a single mouse click, while one participant ($n = 1$, 14.3%) chose a double mouse click, a separate pop-up confirmation window, and left question unanswered. No participants selected the click-and-hold mouse button.

General Preference for Task Delegation. Most participants supported delegation either for individual aircraft assignments ($n = 3$, 42.9%) or specific tasks for all aircraft within their AOR ($n = 2$, 28.6%). Two participants ($n = 2$, 28.6%) were undecided or only supported task-wise delegation as an additional option, and one participant ($n = 1$, 14.3%) opposed task-wise delegation entirely.

Completion Feedback for Delegation. Participants were asked what feedback to provide upon Delegation completion. The most frequent suggestions included: changing the head symbol ($n = 4$, 57.1%), adding more symbols to the label ($n = 3$, 42.9%), and hiding label information ($n = 3$, 42.9%). Only 14.3% ($n = 1$) suggested relying on visual cues like color, font size, or style changes.

Trigger Situations for Delegation. Participants identified scenarios in which they would personally use Delegation. The most common triggers were open routine tasks that the system (D-ATCO) could handle ($n = 6$, 85.7%) and delegation after resolving a conflict for an aircraft that was only passing through a sector ($n = 6$, 85.7%). Delegation after responding to a pilot request was reported by two participants ($n = 2$, 28.6%), while delegation in overload situations was selected by only one participant ($n = 1$, 14.3%). No participants indicated they would never use Delegation.

4.3 User Feedback Redelegation

Need for Radiocheck After Redelegation. Most respondents ($n = 6$, 85.7%) indicated no need for radio check after Redelegation, while one participant ($n = 1$, 14.3%) was undecided. No participants selected yes.

Priority of Redelegation. Participants ranked different aircraft conditions regarding Redelegation priority, where 1 represented the highest urgency. Aircraft in conflict received the highest priority ($M = 1.14$, $SD = 0.38$), followed by aircraft yet outside their sector but in conflict within the AOR ($M = 2.14$, $SD = 0.69$). Aircraft with coordination and pilot requests received lower priority ratings, with an average rank of $M = 3.14$. However, the latter had a higher standard deviation ($SD = 1.21$), indicating more response variability. One participant specified emergencies as an additional high-priority category.

Trigger Situations for Redelegation. Participants identified situations where they expected the system (D-ATCO) to automatically redelegate control without requiring a request. The most common triggers were conflicts where D-ATCO struggles to find a solution ($n = 7$, 100%) and emergencies ($n = 7$, 100%). Other frequently selected triggers included conflicts with shared allocation between humans and the system ($n = 5$, 71.4%) and weather-affected aircraft ($n = 5$, 71.4%). Coordination tasks ($n = 2$, 28.6%) and pilot requests ($n = 1$, 14.3%) were less frequently considered reasons for Redelegation. One participant specified system failure as an additional condition.

4.4 User Feedback Cancel Delegation

Need for Information to Enable Cancel Delegation. All participants ($n = 7$, 100%) indicated they need no information to enable cancellation of delegation, suggesting that they did not see a need for additional confirmation before canceling a delegated task.

Required Information to Confirm Cancel Delegation Completion. Participants could select multiple options regarding how they preferred to observe the completion of a canceled delegation. The most commonly chosen feedback mechanism was a change in the head symbol ($n = 4$, 57.1%). Other preferred methods included extension of label information ($n = 3$, 42.9%), additional symbols/characters in the label ($n = 2$, 28.6%), and changes in label color, font size, or style ($n = 2$, 28.6%). No participants selected attention guidance (e.g., highlighting the head symbol with a filled colored circle).

Need for Radiocheck After Cancel Delegation. All participants ($n = 7$, 100%) indicated that a radiocheck was not necessary after Cancel Delegation.

4.5 User Feedback Request Delegation

Conditions for D-ATCO to Request Delegation. Participants were asked under which conditions the system (D-ATCO) should Request Delegation. The majority ($n = 6$, 85.7%) preferred that D-ATCO should always Request Delegation if it is able to handle a flight. Additionally, three participants (42.9%) supported delegation to balance workload between humans and D-ATCO, while the same number of participants ($n = 3$, 42.9%) agreed with delegation to cap the human workload. No participants selected never.

4.6 Semi-Structured Interview

Analysing the transcripts from the qualitative discussions on the delegation prototype showed that theme that usability and interaction design was frequently mentioned as key point. ATCOs expressed a preference for minimal interaction steps, indicating that even two clicks for delegation might feel excessive. Keeping label information visible at all times to maintain situational awareness. Critiques were directed at the Human-Machine Interface (HMI), particularly regarding the complexity of interactions for routine tasks was also considered as highly relevant. At times, the display of flight levels was unclear, causing confusion about actual clearance levels. To effectively communicate delegation status and avoid interface clutter, ATCOs suggested to consider using symbols or slight modifications to labels. They also favored interactions through radar labels over separate menu options, as the former allows for more direct control.

ATCOs also highlighted the need for seamless delegation. They emphasized that the system should clearly communicate why and when Redelegation occurs, as some found themselves only noticing it after closely examining the display. There was also concern about whether the system sufficiently considered real operational complexities, such as coordination with adjacent sectors and handling unexpected pilot requests.

Cognitive load and situational awareness were further discussed, with some ATCOs acknowledging a steep learning curve with the system, stating that it was not intuitively designed. ATCOs indicated that they would like to have full control over all operations. Some of them were even concerned that Redelegation might be conducted without clear justification. Suggestions included incorporating small tooltips or hover-over explanations to enhance understanding without causing distractions.

When it came to system intelligence and decision-making, ATCOs had expectations that the system should anticipate conflicts and notify them in advance, especially regarding expected coordination issues with adjacent sectors, pilot expectations versus actual system behavior, and situations where Redelegation is unavoidable. ATCOs were also concerned about automation bias. They wondered whether the system would consistently make correct decisions and preferred manual interventions in edge cases. Therefore it would be necessary to easily override automation and ensure that the system does not assume full control without their consent.

In terms of recommendations for improvement, ATCOs urged reducing the number of clicks required for delegation and redelegation to streamline the process. They insisted on keeping label information visible at all times to prevent a loss of situational awareness and improving system transparency by providing clear indications of why a delegation or redelegation occurred. As essential were considered to display information directly in the radar label to minimize the need for additional screens and pop-ups. Additionally, ATCOs considered confirmation steps only as necessary if they serve operational purposes. ATCOs furthermore clearly requested better visual cues like subtle color changes or icons to better differentiate delegation statuses. Tooltips or hover-over expla-

nations should assist them in understanding the decisions of D-ATCO without increasing their cognitive load. Finally, they required that the system considers or detects their personal preferences regarding the timing and manner of delegation decisions, particularly in relation to coordination with other sectors.

5 Discussion and Conclusion

This poster provides a comprehensive analysis of the feedback and recommendations received from ATCOs during the evaluation of the delegation process with a D-ATCO prototype. The ATCOs provided valuable insights into the usability, interaction design, and system intelligence of the prototype.

Our study's findings are limited by the predefined scenarios used for Delegation, Redelegation, and Request Delegation, which may not accurately represent real-world ATC environments due to their narrow scope. Additionally, the D-ATCO system was not fully functional and required pre-allocated aircraft to simulate delegation processes, which introduces an artificial constraint. The relatively small number of ATCOs involved in our study also limits the statistical power of our results. It's also possible that some usability aspects were not thoroughly explored during discussions, potentially affecting the validity of our findings.

To build upon our research, it is envisaged to test delegation functionalities in real-time ATC simulations with dynamic traffic and realistic sector constraints. This can help to assess whether the delegation approach aligns with ATCO's operational decision-making. Moreover, it's crucial to investigate how trust in the system evolves over prolonged use to ensure its long-term effectiveness.

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