

EVALUATING HUMAN-MACHINE-TEAMING CONCEPTS FOR A HIGHLY AUTOMATED GROUND CONTROLLER WORKING POSITION

Lennard Nöhren[1], Anna Simon[1] & Meilin Schaper[1]

[1]German Aerospace Centre, Institute of Flight Guidance, Lilienthalplatz 7, 38108 Braunschweig, Germany

Abstract

Due to increasing traffic loads and air traffic controller (ATCO) shortages, air traffic delays are increasing, causing high costs and reducing the attractiveness of air travel. A higher degree of automation in air traffic management systems could help to address this issue by allowing the same number of ATCOs to handle higher traffic loads. To realize a high degree of automation, while still keeping the ATCO in the loop for quick interventions in case of problems, a human-machine-teaming concept can be applied: Some tasks are performed fully autonomously by a digital ATCO, while others are still performed by the human ATCO. This paper presents different methods how the tasks could be distributed between human and digital ATCO as well as several methods how the human ATCO could intervene in the automation. These methods were evaluated by 11 ATCOs, gathering feedback which are the most fitting methods for an apron and ground controller working position. Based on the feedback, a distribution method was selected, where a specific area is assigned to be controlled by the digital ATCO. For the intervention an improved method was developed based on comments of the participating ATCOs that combines a fast intervention possibility with high flexibility for the re-delegation to the digital ATCO. The selected methods will be implemented in a prototypical system in the future.

Keywords: Air Traffic Management, Human-Machine-Teaming, Ground Air Traffic Management, Automation, Digital Controller

1. Introduction

Air traffic delays have been rising in recent years due to air traffic controller (ATCO) shortages as one of the main contributing factors [1]. EUROCONTROL estimated that more than 700 ATCOs were missing in 2022 [2] and the International Federation of Air Traffic Controllers' Associations (IFATCA) estimated costs of more than 2 billion Euros due to delays in 2024 alone [3]. This problem is expected to intensify with rising demand for air travel [4]. One way to tackle this issue could be an increase of automation to enable the same number of ATCOs to handle higher traffic volumes. But increasing automation in a safety critical environment such as air traffic management (ATM) harbours many risks, like degraded situational awareness of the operator [5]. Therefore, the Single European Sky ATM Research Programme (SESAR) created a roadmap depicting steps to reach high automation levels within the next 20 years while still abiding to the ATM safety standards [6]. This roadmap contains multiple levels of automation ranging from low automation to confined automation and describes recommended steps and time frames to reach the higher levels. Systems with high automation levels should be able to decide and implement all tasks within a defined scope completely independent from human ATCOs. Such an automated system can be called digital ATCO [7], as it performs the same actions as a human ATCO within its limited scope. One area that can be used to apply this high degree of automation is the apron and ground controller working position, responsible for managing the traffic on the apron(s) and taxiways. Applying automation on the ground movement

https://doi.org/10.71945/icas2026_0302

managing position has the advantage that in case of an emergency or system failure, all flights can stop and hold their current position. Furthermore, the International Civil Aviation Organization (ICAO) Advanced Surface Movement Guidance and Control System (A-SMGCS) standard can be used when developing automated systems in this area. It contains many requirements and expectations for advanced surface management systems like routing service and alerts [8]. A digital ATCO that follows all these requirements reliably, will already fulfil the most important safety standards on the ground.
The foundation for developing a feasible human-machine teaming concept for apron and ground controller working positions is described in this paper: We developed multiple different human-machine-teaming methods for air traffic ground control, distributing the tasks between the digital and the human ATCO while keeping the human ATCO in an active role. The different methods were presented to 11 ATCOs, their feedback was evaluated and the conclusions are presented here. Based on the results, the preferred method is selected for future work.

2. Related Work

Human-machine-teaming or human-autonomy-teaming has been an important research topic since at least the 1990s when the automation paradox was first described: An increase in automation might decrease safety due to degraded situational awareness and reduced operator vigilance [5]. This prompted a shift from pure automation toward collaborative human-machine systems [9]. Multiple benefits of human-machine-teaming have been observed compared to full automation. Automation might fail in novel or complex situations, or even regular situations due to a glitch, leading to "automation surprises" for humans supervising the system [10]. This can be prevented with better human-machine-teaming where complementary strengths of humans and automation are utilized. While humans excel at adapting to new situations, problem solving and ethical decisions, automation can handle massive data analysis, pattern recognition and routine tasks with maximum efficiency and consistency. Human-machine-teaming increases trust and allows better shared mental models between humans and automation improving understanding of decisions and preventing over-reliance, compared to supervised automation [9].
Research in human-machine-teaming has also increased in the ATC domain in recent years, partly due to research incentives like SESAR. The consortium of the SESAR3 project ASTAIR (Auto-Steer Taxi at Airports) developed an Artificial Intelligence (AI) tool that is capable of planning trajectories for aircraft and tow tugs in the movement area of airports ensuring conflict-freedom by adjusting the speed profiles. The suggested trajectories are sent to the responsible Ground ATCO who checks the recommendations and authorises AI to guide a flight or vehicle along the taxi-route. Further, AI supports the Ground ATCO with suggestions for the timing of pushback and engine start-up which are then cleared by the Ground ATCO [11]. New human-machine-interfaces (HMIs) shall support the human-machine-teaming [12]. A Human-in-the-Loop (HITL) simulation as validation for TRL 1 was carried out with three ATCOs. The results show that the ATCOs rated the AI-tool as useful, effectively assisting decision-making with the ASTAIR system supporting the collaboration between human and AI. However, the ATCOs stated challenges with the HMI design, the division of responsibilities between human and AI as well as the cognitive load [13]. The SESAR project CODA (Controller Adaptive Digital Assistant) provides a concept to dynamically adapt the level of support by an automated system based on the workload of the ATCO identified by (neuro)physiological measurements as well as current and future traffic parameters. A workshop with three former ATCOs focussed on gathering HMI design guidelines as well as adaptation strategies for the CODA system, e. g. that critical tasks always remain with the human ATCO [14]. Preliminary simulations already showed that the ATCOs perceived workload could be reduced in scenarios with a high traffic density when CODA is applied [15]. Hurter et al. discuss further projects carried out within SESAR focusing on neurophysiological measures to evaluate human-AI-teaming in the context of ATC [16].
The DLR research project LOKI developed a human-machine-teaming concept for the enroute working area, coining the term digital controller or digital ATCO [7]. This digital ATCO is able to assess the traffic situation, generate action plans and perform the necessary tasks to assist the human ATCO in handling higher traffic loads. The default human-machine-teaming approach of this system is a hybrid mode, where the control of flights is initially allocated either to the human or digital ATCO [17] and can be delegated by the human ATCO to the digital ATCO or vice versa at any time [18]. The digital ATCO

will then perform all relevant tasks for these flights within the sector. Multiple tools were developed to support the cooperation between human and digital ATCO to improve situational awareness and create a shared mental model [19], for example a dedicated human autonomy teaming interface [20]. Previous HITL experiments for the apron and ground controller at DLR used an experimental decision support tool called TraMICS [21]. It contains the most important functions of a surface management system, like real time trajectory generation and optimisation, conformance monitoring, conflict detection and conflict resolution. This tool was enhanced to be a digital ATCO, called AutoTraMICS, that takes and implements decisions based on the adaptive trajectory planning. No dedicated human-machine-teaming concept was used in the system. Instead, it relied on full automation. The main focus of the human ATCO changed from planning and executing commands to monitoring the digital ATCO when using this version of AutoTraMICS [22]. ATCOs participating in validations of AutoTraMICS expressed concerns about skill degradation and the challenges arising from a different behaviour of the system compared to typical trained ATCO behaviour [23].

3. Concept

The human-machine-teaming concept for apron and ground controller working positions, described in the following, consists of two main parts: distribution methods and intervention methods. The different distribution methods describe how tasks are partitioned between human and digital ATCO. The intervention methods describe how the human ATCO can intervene into the planning or execution of the digital ATCO. This is important, as we assume that the human ATCO is still responsible in case of unexpected system failure or human pilot request. Therefore, they have to be able to supervise the digital ATCO and intervene in case it is necessary. In this work, we focus on a combined apron and ground controller working position, however the methods could also be applied to other controller working positions.
Four distribution methods and four intervention methods were elaborated as high-level proposals and presented to ATCOs to evaluate their feedback. Each distribution method could be combined with each intervention method for the final teaming concept. The methods are described in the following subsections.

3.1 Definitions

To simplify the description of the methods, some definitions and wordings are provided:

- Area of responsibility (AOR): ATCOs have a strictly defined AOR in which they are responsible for all flights. This AOR is defined for each airport in the Aeronautical Information Publication (AIP). When a digital ATCO works together with a human ATCO, the AOR remains the same, but might be split between or shared by the two. The human ATCO still has the final authority over all flights within the AOR, even if they are currently assigned to the digital ATCO.

- Process in AOR: Within an AOR there are certain tasks that need to be performed for all flights. The collection of all tasks for a flight in an AOR is called the *complete process* in this paper. For ground and apron controllers this usually comprises pushback and taxi instructions, but may also include start-up and runway crossings, e.g. elbow-coordinated with tower. Which tasks need to be performed exactly depend on the flight and the AOR.

- Handover: When a flight reaches the border of an AOR, the control needs to be transferred to the ATCO controlling the neighbouring AOR. This is done by instructing the pilot to contact the radio frequency of the next AOR and, depending on the used system, by clicking a button in the controller working position.

- Delegation: When the human ATCO assigns the control of a flight to the digital ATCO or vice versa. In contrast to handover, which is between two AORs, the delegation happens within the same AOR.

- Operational design domain (ODD): The digital ATCO needs to be able to handle the traffic under most circumstances. But when the traffic situation becomes too complex, an emergency occurs or a human response is requested by a pilot, the digital ATCO can no longer handle the

affected flights. To specify the scope in which the digital ATCO can work reliably, an ODD can be defined [24]. When a flight assigned to the digital ATCO leaves this ODD, the control needs to be delegated to the human ATCO and they should be notified by some form of attention guidance.

- Modifying a flight: The human ATCO can not only give direct instructions to flights, but also apply constraints or adapt the planning and future execution of flights under control of the digital ATCO. For that, we use the term *modifying the flight* in the remaining descriptions.
- Implicit and explicit delegation: The different intervention methods contain different options how a delegation can be initiated. In case the delegation is initiated by the human pressing a dedicated delegation button, it is called *explicit* delegation in the following descriptions. In case the delegation is initiated by the system, e.g. due to time constraints, it is called an *implicit* delegation. In both cases, the control is delegated as described above.

3.2 Distribution Methods

There are many ways how the different tasks of ground and/or apron controllers can be distributed between a human and a digital ATCO to keep the human ATCO in an active role while using the benefits of automated systems. We assume that the tasks and the AORs of the working position will stay in principle as it is today. Inside the AOR we intend to share tasks between human and digital ATCO. The human ATCO will plan and implement their allocated tasks and additionally supervise the digital ATCO, which will plan and implement the tasks it is assigned to. We created four different distribution methods (DM) based on research and expert knowledge:

3.2.1 DM1 - Distribution by number of flights

A very simple method to distribute task share would be to assign each flight either to the human or the digital ATCO based on a percentual allocation key (Figure 1). A flight would stay under the control of the human respectively the digital ATCO for its complete process in the AOR. The digital ATCO executes all required tasks for the flights under its control and the human ATCO would perform them for flights under their control. Therefore, no delegation of control between the human and the digital ATCO is required in the AOR, unless the human ATCO specifically requests so or a flight leaves the ODD of the digital ATCO. In this method the task share of the human ATCO could be adapted flexibly whenever desired by simply changing the number of flights currently under their control. For example, under normal operations an even distribution might be targeted, while in an emergency situation, a distribution of 20 % human and 80 % digital ATCO might be favoured to allow the human ATCO to focus on the emergency.

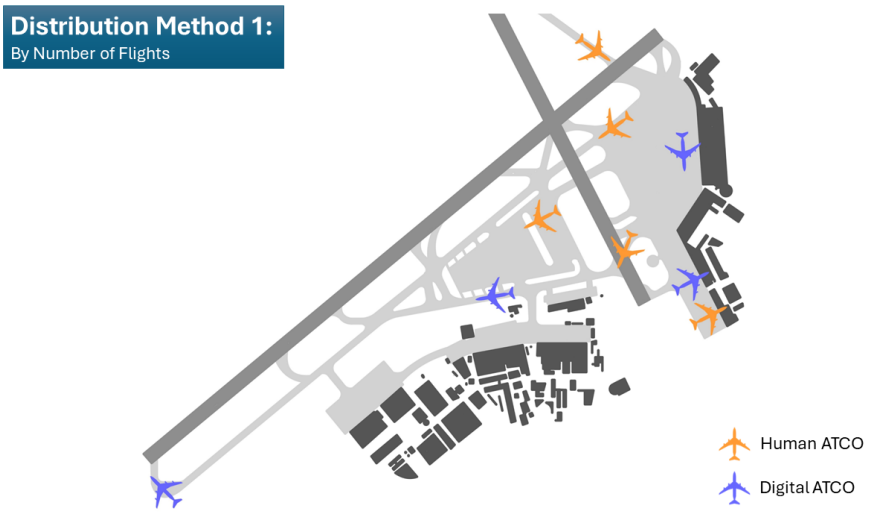


Figure 1 – Illustration of DM1. A certain number of flights are under control of the human ATCO (orange), the remaining flights are controlled by the digital ATCO (blue).

3.2.2 DM2 - Distribution by flight properties

A similar but more structured method to distribute the task share would be to base the allocation key on certain properties of the flights. As exemplarily depicted in Figure 2, all departures could be under control of the human ATCO while all arrivals would be controlled by the digital ATCO. This would make it simpler for the human ATCO to keep an overview of which flights are currently under their control, but would reduce the flexibility to adapt the task share. Just as in DM1, no delegation between human and digital ATCO is necessary in the AOR, unless the human ATCO specifically requests so or a flight leaves the ODD of the digital ATCO.

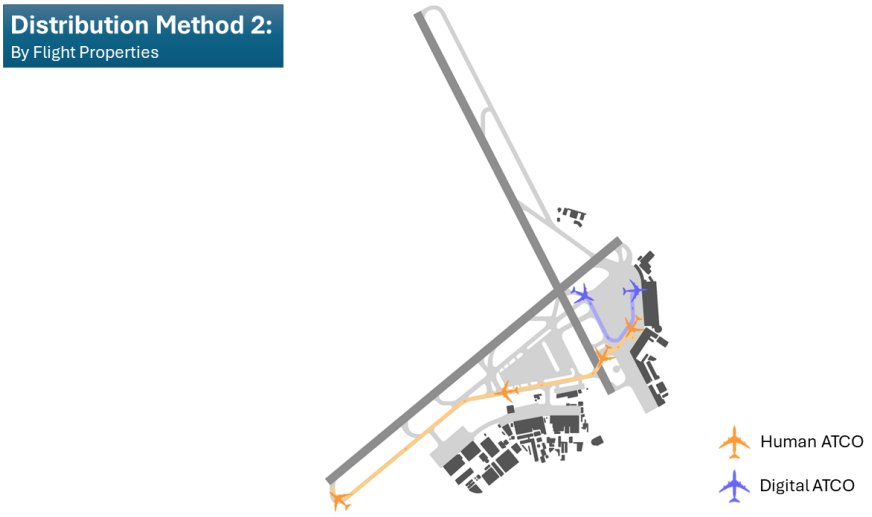


Figure 2 – Illustration of DM2. All flights with a specific property are under control of the human ATCO (orange), the remaining flights are controlled by the digital ATCO (blue). In this example, all departures are under human control and all arrivals under control of the digital ATCO.

3.2.3 DM3 - Distribution by airport areas

Instead of assigning certain flights for all their tasks in the AOR to either the human or digital ATCO, the AOR itself could be distributed between them (Figure 3). Consequently, the area in which the

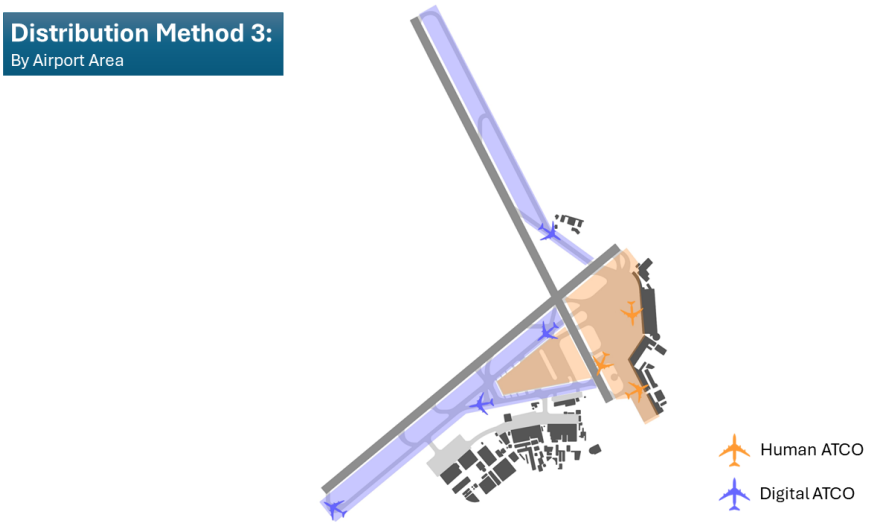


Figure 3 – Illustration of DM3. Some areas and all flights within are under control of the human ATCO (orange) and the other areas and flights within are controlled by the digital ATCO (blue). In this example, the aprons are under human control and the remaining taxiways are under control of the digital ATCO.

flight is currently located distinguishes whether it is under control of the human or the digital ATCO. Normally, this method results in a strict spatial division between flights controlled by human or digital ATCO. As a result, the number of direct interdependencies of flights controlled by the two types of ATCOs can be reduced compared to DM1 and DM2. In contrast, it would necessitate a delegation between human and digital ATCO at the borders of these areas within the AOR. This method aligns with operational practices, as ground and apron control at large airports are divided into different AORs and handled by different human ATCOs, enhancing familiarity.

3.2.4 DM4 - Distribution by tasks

The fourth distribution method is a distribution by specific tasks. Figure 4 shows an example with the start-up and pushback clearance as well as the handover to the tower frequency being under control of the digital ATCO, while all other tasks are controlled by the human ATCO. In this method the control of flights would be delegated based on the next oncoming task. For example, flights that are still parked at their gate are under control of the digital ATCO, as the next task is pushback. As soon as the pushback is completed, the control is delegated to the human as the next task is instructing and monitoring the taxi procedure. Depending on the implemented division of tasks, there might be several delegation actions needed throughout the complete process of each flight in the AOR.

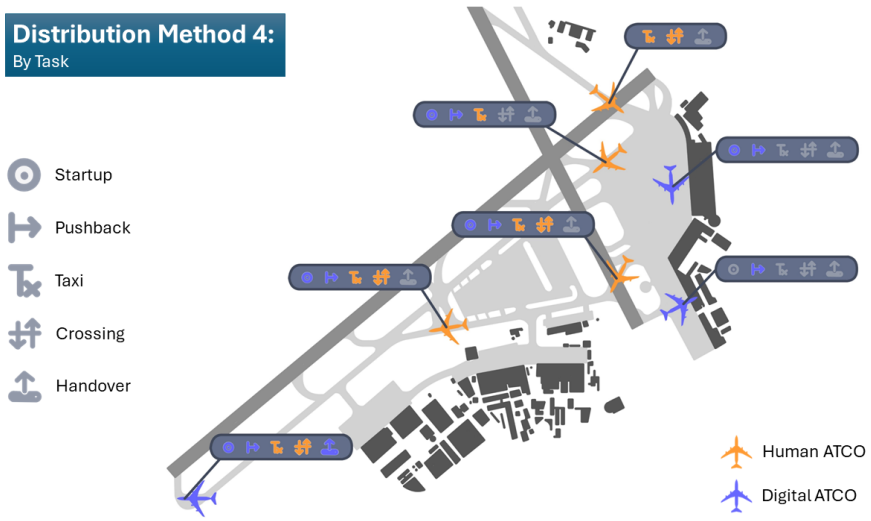


Figure 4 – Illustration of DM4. Certain tasks are under control of the human ATCO (orange) and the remaining tasks are controlled by the digital ATCO (blue). In this example, the latter controls start-up, pushback and handover.

3.3 Intervention Methods

Regardless of how the tasks are distributed between human and digital ATCO, the human ATCO will always need to have the ability to intervene into the actions of the digital ATCO. This is especially important in case a flight leaves the ODD of the digital ATCO. To enable the human ATCO to intervene for flights that are currently not under their control, we proposed the following four intervention methods (IM):

3.3.1 IM1 - Explicit delegation and explicit re-delegation

In this intervention method (Figure 5) the human ATCO would need to initialise the delegation of the flight from the digital ATCO if they want or need to intervene. The digital ATCO would immediately delegate the flight to the human ATCO, allowing them to modify the flight as desired. When the human ATCO completed the modifications, the flight can be delegated back to the digital ATCO manually or kept under human control. However, the digital ATCO would be forbidden to overwrite any actions or modifications performed by the human ATCO. This method guarantees at all times a clear assignment of control to either the human or the digital ATCO.

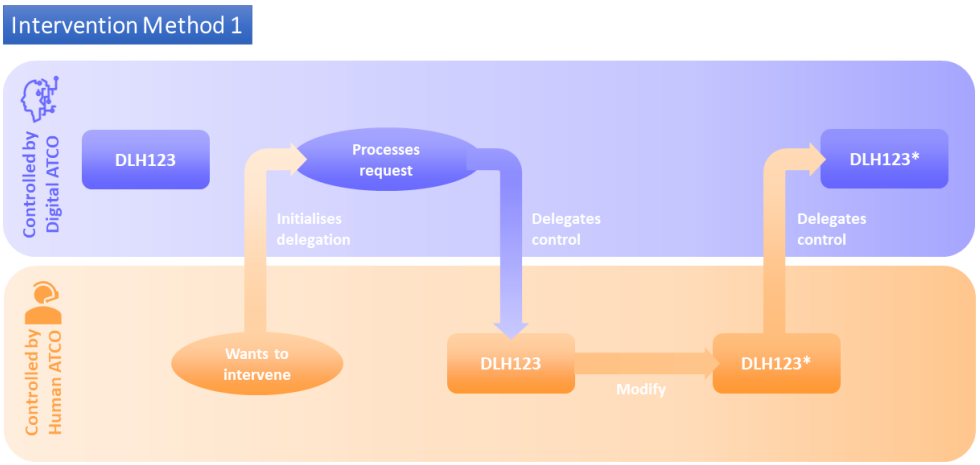


Figure 5 – Schematic illustration of IM1. Flight DLH123 is initially under control of the digital ATCO. To modify the flight, the human ATCO first initialises the delegation of control which is performed by the digital ATCO. After the human ATCO completed their modifications, the flight can be delegated back to the digital ATCO. The * marks the modification of the flight.

3.3.2 IM2 - Explicit delegation and implicit re-delegation

The second intervention method (Figure 6) is very similar to IM1, with an adaption to the procedure for delegating the control back to the digital ATCO. Instead of being explicitly returned by the human ATCO, the digital ATCO takes back the control of a flight a certain time period after the last modification was performed by the human ATCO to this flight. This method saves the human ATCO the action of a manual re-delegation and by that reduces the number of tasks the human ATCO has to perform. It also acts as a kind of safety net in case the human ATCO forgets that they took over the control of a flight.

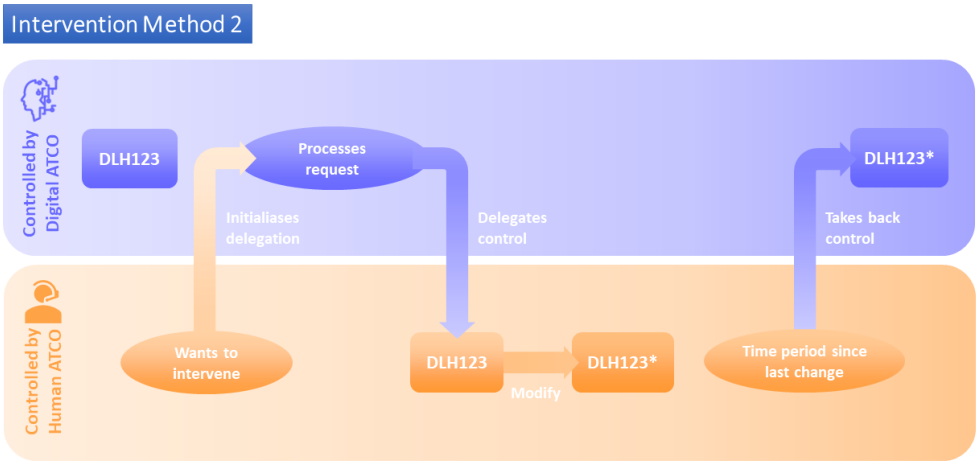


Figure 6 – Schematic illustration of IM2. Flight DLH123 is initially under control of the digital ATCO. To modify the flight, the human ATCO first initialises the delegation which is performed by the digital ATCO. After some time without additional modifications, the digital ATCO takes back control.

3.3.3 IM3 - Direct intervention with no delegation

The direct intervention method (Figure 7) aims to reduce the number of actions the human ATCO has to perform to intervene into the actions of the digital ATCO. In this method, the control of the flight is not delegated, instead the human ATCO can directly modify the flight, while it remains under control of the digital ATCO. As in all other methods, the digital ATCO is not allowed to overwrite any modifications performed by the human ATCO.

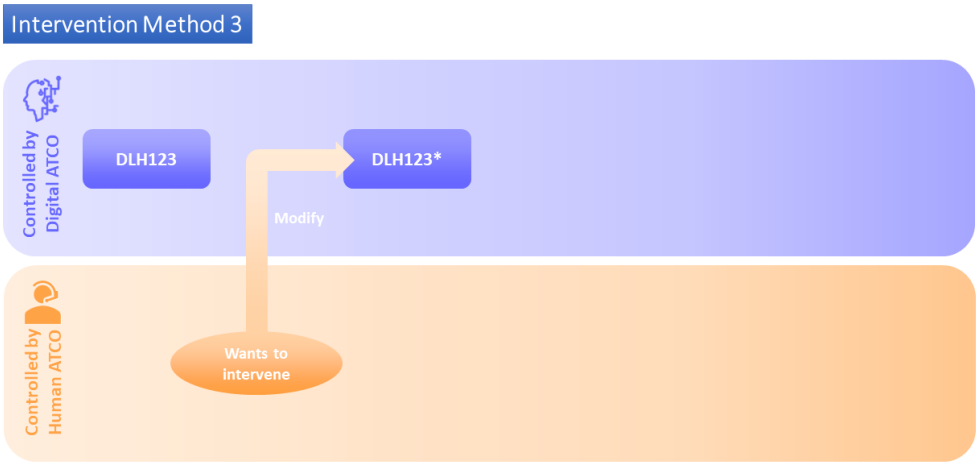


Figure 7 – Schematic illustration of IM3. Flight DLH123 is under control of the digital ATCO. To modify the flight, the human ATCO simply performs the desired modifications. The control is not delegated to the human ATCO.

3.3.4 IM4 - Direct intervention with implicit delegation and explicit re-delegation

The fourth intervention method (Figure 8) combines elements of IM3 and IM1: The human ATCO can directly modify flights that are under control of the digital ATCO. But as soon as this occurs, the control of the flight is delegated to the human ATCO. When the human ATCO has concluded the modifications, they can delegate the flight back to the digital ATCO or keep it. This method allows faster access to every flight while simultaneously guaranteeing a clear assignment of control to either the human or the digital ATCO at all times.

4. Evaluation

This chapter describes the methods applied for the evaluation of the concept, including the sample of validation participants (VP), followed by the results, differentiated by distribution and invention methods.

4.1 Method

A semi-structured interview was chosen as method to receive feedback from ATCOs to the topic human-machine-teaming including distribution and intervention methods. The semi-structured interview followed a HITL simulator study, evaluating the feasibility of sustainable taxi in different system support conditions from the controllers' perspective. 11 ATCOs holding an Apron and/or Tower (including Ground) license from six German airports participated in the HITL study and the following interview, one at a time. The HITL experiments itself are not the focus of this work. However, they gave the VPs an impression of automation and intervention. Therefore, some aspects of the experimental design of the HITL study are relevant for the interview and will be briefly outlined below.

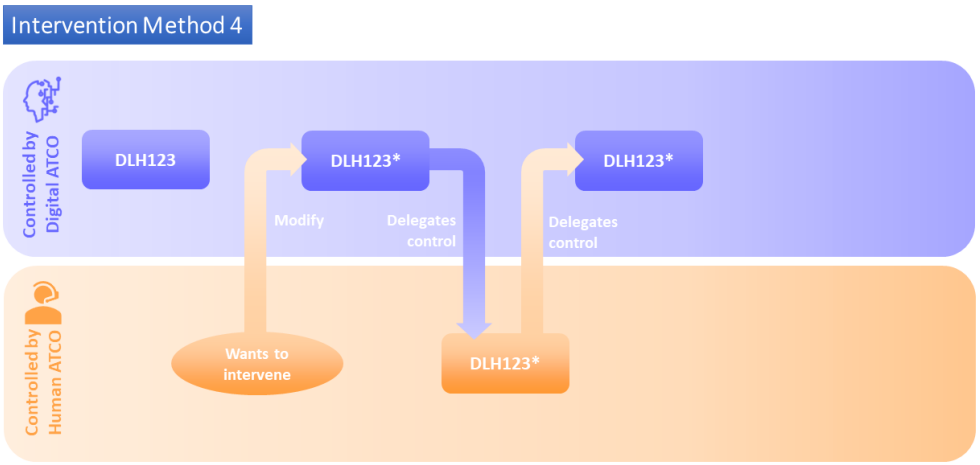


Figure 8 – Schematic illustration of IM4. Flight DLH123 is initially under control of the digital ATCO. To modify the flight, the human ATCO simply performs the modifications. The digital ATCO immediately delegates the flight to the human ATCO when this occurs. Afterwards the human ATCO can delegate the control back to the digital ATCO.

4.1.1 HITL study design

The study was conducted in DLR's 360-degree tower simulator, equipped with one *Ground* and one *Tower* working position, using a modified topology of Hamburg (EDDH) airport (Figure 9). The role of the VPs was *Ground*, defined as being responsible for all ground and apron movements as well as issuing start-up instruction. The *Tower* working position was staffed by DLR colleagues and managed the runways. The used runway configuration was RWY 05 for take-off and RWY 15 for landing, requiring runway crossings. Those were performed using elbow-coordination between *Ground* and *Tower*. The control of the flights stayed at *Ground* until handover to *Tower* on taxiway D1 for departures, mostly after passing the intersection to D3. The study consisted of multiple different conditions. One of them was Automation: AutoTraMICS [22] controlled all flights at the *Ground* AOR, took decisions based on the planned and maintained trajectories and sent instructions via datalink to the simulation pilots. The digital ATCO was not allowed to perform runway crossings. Therefore, the VP still had to coordinate them with *Tower* and had to input the crossing instruction into the CWP manually. This input triggered a datalink message to the simulation pilots. The human ATCO was able to intervene at any time, e.g. by assigning other routes than planned, issuing instructions earlier than planned or simply using the radio to ask for further information. This condition correlates most closely to DM3 (distribution by airport areas) with the complete AOR assigned to the digital ATCO or to DM4 (distribution by tasks), with only the runway crossing being under control of the human ATCO. However, no delegation to the human ATCO was performed, i.e. all flights stayed under control of the digital ATCO throughout the complete process in the AOR. If the human ATCO intervened, IM3 (direct intervention with no delegation) was applied. Each VP experienced the automation condition two times: once with and once without sustainable taxi operations. Each time a different 45-minute scenario containing a high traffic load for EDDH was used. Each VP received a briefing and a training before the first experimental run and a de-briefing after each run. A detailed paper of the whole HITL study is in preparation, single aspects are already evaluated [25].

4.1.2 Improved human-machine-teaming interview

After the HITL study was de-briefed, the semi-structured interview started. It was introduced by stating the intentions of the authors: To gather opinions and information about a better human-machine-teaming for the apron and ground controller role by operational experts. First, the four distribution methods were explained with an explicit exemplary distribution between human and digital ATCO

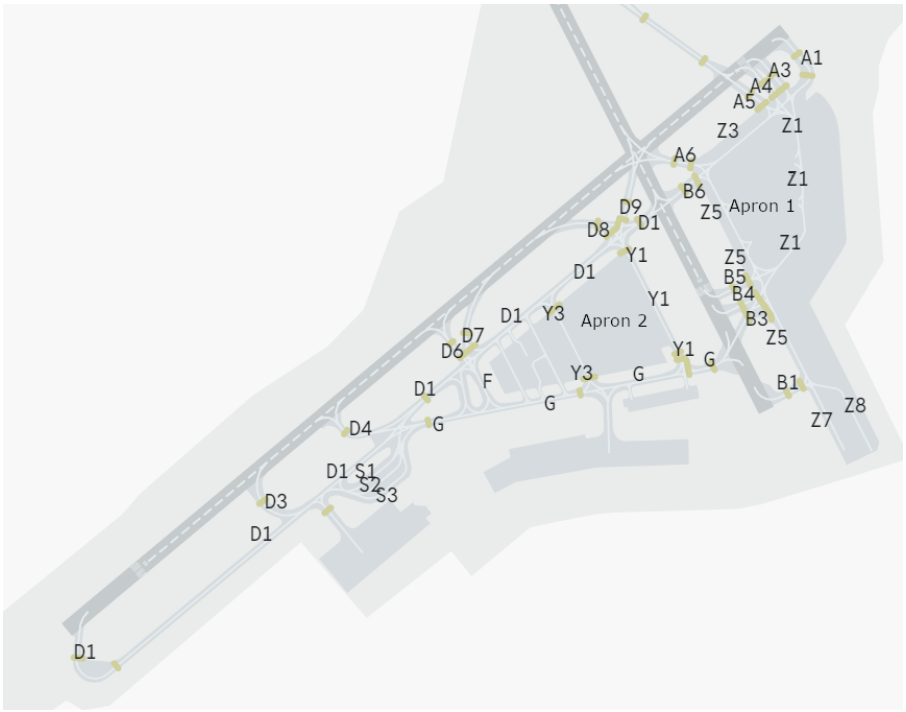


Figure 9 – The airport topology used in the evaluation with taxiway and apron designators.

for each method. These examples are similar to the ones shown in Figure 1 to Figure 4 but were presented in written form with oral explanations instead of the depictions. The VPs were invited to comment the distribution methods. While some VPs shared their opinion about all four methods or compared them with each other, others only discussed their favourite method and explained details on this chosen one. When discussing a specific distribution method, the VPs were asked to provide some additional details for the task distribution. For example, for DM3 they were asked for their favoured areas for automation and favoured areas for human control in two different ground movement charts: One of the airport they just experienced in the HITL study and one of the airport they currently work at. Second, the four intervention methods were orally explained and presented with depictions similar to Figure 5 to Figure 8. Again, the VPs were asked about their opinions and thoughts about the methods. Not every VP commented on every presented intervention method. Further questions were included in the semi-structured interview that are not evaluated in this work. The cited statements in the following sections reflect the personal opinions of the different VPs and might be contrary to comments made by other VPs.

4.2 Results for Distribution Methods

4.2.1 DM1 - Distribution by number of flights and DM2 - Distribution by flight properties

Distributing the task share between human and digital ATCO for specific flights and their complete process in the AOR with an allocation key was rejected as distribution method in both of the presented versions: VPs would neither choose this method with a percentual allocation key (DM1) nor with it being based on the flight properties (DM2). They argue that having flights controlled by different ATCOs within the same area is problematic due to a lack of synchronisation. Therefore, they cannot imagine to work in such a set-up.

4.2.2 DM3 - Distribution by airport areas

This distribution method was positively rated by all VPs. The clear spatial separation of flights controlled by the different types of ATCOs as consequence of the subdivided areas of the AOR would overcome the stated drawbacks of DM1 and DM2. The required additional delegation between human and digital ATCO within the AOR was not perceived as a drawback. It was stated that they are used to work with different ATCOs being responsible for different areas of the airport (e.g. apron, ground, tower). Two VPs that have to deal with a high volume of VFR (visual flight rules) traffic at

their airports commented that VFR flights are often executed by non-professional pilots with lower equipped aircraft. Therefore, VFR flights are assessed as unsuitable for being under control of a digital ATCO. With VFR flights as part of the traffic mix of a certain airport, the distribution by area could therefore still lead to situations with flights controlled by different kinds of ATCOs within the same area like in DM1 and DM2.

When asked for general opinions about DM3, the following statements were made: Two of the VPs stated that the digital ATCO should handle areas with a low risk of conflict occurrence, i.e. areas with few intersections. Areas with lower traffic volumes seem the most suitable for the digital ATCO in the opinion of two additional VPs. Four of the VPs highlighted limited movement options, a low number of intersections or clear and easy rules for flight movements as important factors to let areas be controlled by the digital ATCO. In general, the layout of the specific airport would decide whether a certain area is appropriate for being controlled by the digital ATCO.

Looking explicitly at the area distribution proposals of the VPs for the experienced airport in the HITL study (Figure 9), a diverse picture arises of which areas are rated as suitable for the digital ATCO, with some ideas being contradictory to statements by other VPs: Three of the VPs preferred the digital ATCO to control all aprons, while all other areas stay with the human ATCO. Those three VPs hold a licence for “Apron and more”. Further three VPs prefer mainly the taxiways used by departing flights west of RWY 15 to be controlled by the digital controller: The extent varies from only D1 and G without the taxiway intersection to G and D1 after S to the complete taxiways D1 and G. Additionally, three VPs expand the area controlled by the digital ATCO in their preferred version to everything west of RWY 15. The six VPs assigning mainly taxiways and simpler aprons to the digital ATCO all hold an Apron-only licence. Further, two of them would additionally assign Apron 1 south of B1 to the digital ATCO. The remaining two VPs, both with a licence for “Apron and more”, would prefer that the digital ATCO controls all areas of the airport except the runways and the related task of runway crossing. This maximally expanded area controlled by the digital ATCO equals the set-up that was used in the HITL study prior to this interview. All envisioned versions share one commonality: The runways and all movements directly affecting them should always stay under control of the human ATCO. Figure 10 shows the areas for the digital ATCO that result when aggregating the feedback of all VPs and the number of VPs selecting them.



Figure 10 – Schematic depiction of areas that were recommended for the digital ATCO by the VPs. The numbers specify the total amount of VPs selecting this area as part of their favoured distribution.

Some VPs gave feedback on how the areas should be distributed at the airport they currently work at. In most cases this feedback was consistent with the feedback for the airport used in preceding HITL study, i.e. areas with lower traffic load or low complexity are suggested to be handled by the digital ATCO whereas more complex areas should stay under control of the human ATCO. Apart from that, VPs from smaller airports had doubts that an automation concept could work at their airport due to the high amount of VFR traffic, which was seen as unsuitable for a digital ATCO. Another VP mentioned that the airport area that is mostly used for cargo could be handled by the digital ATCO.

4.2.3 DM4 - Distribution by tasks

Distributing the tasks between the human and digital ATCO is a conceivable distribution method for more than half of the VPs. It was fully rejected by three VPs. The other eight VPs were asked in the interview to assign the tasks necessary in the AOR to the human or digital controller. Which tasks are necessary was neither explicitly defined nor explicitly asked for, therefore the number of received answers per mentioned task varies (Table 1).

Table 1 – Answers received by VPs for DM4 - Distribution by tasks

	Answers received	Human ATCO	Digital ATCO
Start-up	8	0	8
Pushback	8	5	3
Taxi	6	6	0
Crossing	7	7	0
Handover	4	0	4
Emergency	1	1	0
Departure Clearance	1	0	1

The summarized answers in Table 1 show for most of the tasks in the AOR a common opinion between all VPs: Start-up and handover to the next AOR are clearly rated suitable for the digital ATCO. These tasks were often commented as being simple and with low risk. In contrast, the runway crossing should always remain with the human ATCO. This is in line with the responds received for DM3 where the runway and all related movements are assigned to the human ATCO independent of the distribution of all other areas between human and digital ATCO. All six VPs, who responded explicitly to the task taxi, would prefer this task to be controlled by the human ATCO, although some wished for route suggestions by the digital ATCO. Further two VPs mentioned this task in combination with DM3, a distribution by airport areas. These combinations include the following ideas: Taxi is a task controlled by the human ATCO but the taxiways D1 and G at the used airport (Figure 9) are under control of the digital ATCO; start-up and pushback are controlled by the digital ATCO as well as taxi on selected aprons while on more complex aprons the task taxi is under control of the human ATCO. Both versions show a split of the task taxi between the different types of ATCOs depending on the airport area. Therefore, these comments implicitly show the preference of DM3 of these VPs. The most disputed task is pushback: Three VPs would assign this task to the digital ATCO while five prefer this task to be controlled by the human ATCO. For the latter, they commented that they prefer all movements to be done by the human ATCO to be aware of all commencing movements within the AOR.

4.3 Results for Intervention Methods

4.3.1 IM1 - Explicit delegation and explicit re-delegation

This intervention method was not favoured by any of the VPs. The initialisation of the delegation by the human ATCO was commented by several VPs as too time-consuming, especially in urgent or emergency situations and unnecessary as the digital ATCO cannot reject the delegation. Nevertheless, three VPs mentioned that the manual initialisation by the human ATCO combined with the manual re-delegation back to the digital ATCO is a point in favour because both actions have to be explicitly carried out by the human ATCO.

4.3.2 IM2 - Explicit delegation and implicit re-delegation

None of the VPs would choose this intervention method. As for IM1, the initialisation of the delegation by the human ATCO is rated unnecessary and time-consuming. The automatic re-delegation to the digital ATCO after a certain time period is perceived as impractical by two VPs, especially if further modifications to the flight might become necessary when it is already re-delegated back to the digital ATCO. In contrast, one VP stated that the automatic delegation after a certain time span is preferred to the manual delegation in IM1 as the delegation back to the digital ATCO cannot be forgotten in this case.

4.3.3 IM3 - Direct intervention with no delegation

This intervention method is the one that was used in the HITL study prior to the semi-structured interview. Three VPs would prefer this intervention method, another one would choose it for smaller modifications like setting a holding point for a flight while more complex modifications should be carried out with IM1. The method is rated as being the easiest and most time-efficient one without the risk of forgetting the delegation back to the digital ATCO. It is stated that the method must be implemented in a way that the digital ATCO has to adapt its planning to the modifications carried out by the human ATCO and actions for the same flight at the same time by the different types of ATCOs must be impossible. One VP remarked that for safety reasons the control should always be clearly assigned to one type of ATCO, which is not given with this intervention method.

4.3.4 IM4 - Direct intervention with implicit delegation and explicit re-delegation

This intervention method would be chosen as the preferred one by four VPs. Another VP could imagine to work with it for modifying route instructions. The method is rated higher than IM1 as it saves the additional delegation initialisation action and allows direct intervention with clear assignment to one type of ATCO, in contrast to IM3.

Additional to the four presented intervention methods, three of the VPs combined IM2 and IM4 to a fifth option (IM5): The human ATCO can directly intervene and modify a flight. By doing so, the control for this flight is delegated to the human ATCO. But instead of explicitly re-delegating it back to the digital ATCO, this is carried out implicitly a certain time span after the last action for the flight by the human ATCO. The VPs favour that the control is delegated to the human when intervening rather than staying with the digital ATCO like in IM3 and therefore prevents contrary actions for the same flight by the different types of ATCOs. At the same time this new method combines a direct intervention (and therewith implicit delegation) with an implicit re-delegation back to the digital ATCO, so that it cannot be forgotten by the human ATCO. This results in a more intuitive concept, where an implicit delegation is combined with an implicit re-delegation back to the digital ATCO.

As general comments about the intervention methods three VPs stated that the pilots should get some kind of information to know which type of ATCO is currently controlling the flight. Additionally, one VP pointed out that the option of communication with the human ATCO via radio should always be available.

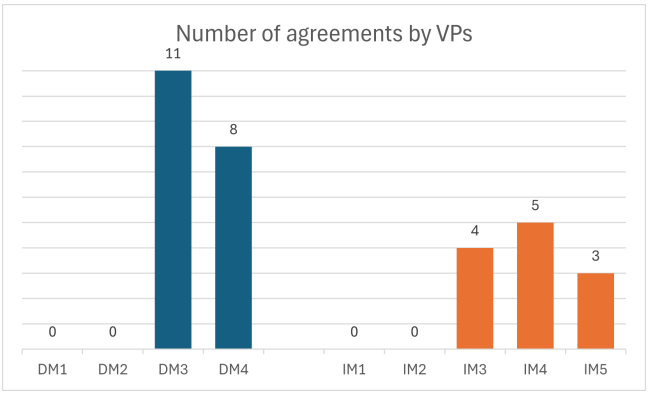


Figure 11 – Each distribution and intervention method with the number of agreements.

In summary, Figure 11 shows the agreements to each distribution and intervention method. Each VP could choose multiple distribution or intervention methods as acceptable. For example, eight VPs chose both DM3 and DM4 as acceptable.

5. Conclusion

Based on the answers received in the semi-structured interviews with 11 ATCOs (Figure 11), the best fitting method for distributing the task share in a teaming of human and digital ATCO and the best fitting intervention method are chosen.

As best fitting distribution method DM3 – distribution by airport areas – is selected. This method was positively rated by all VPs with its clear distinction of controlled areas and unambiguous separation of responsibilities of the different types of ATCOs. In detail, the authors propose that the digital ATCO controls taxiways with a limited number of intersections as well as aprons with clear and easy rules for flight movements, for example the western area of the example airport in Figure 10. This is in line with the statements by the VPs and their wish of a low risk of conflict occurrence in areas controlled by the digital ATCO. The human ATCO stays responsible for more complex areas (e.g. complex aprons) and all movements directly affecting the runways. Further, the supervision of the whole AOR is incumbent on the human ATCO. For a specific airport, the area distribution is dependent on its layout, traffic rules and traffic volumes and has to be elaborated on a case-by-case basis. Two VPs even wanted the digital ATCO to control all areas apart from the runways. This configuration may be an option for smaller airports, where one ATCO works in a combined Tower and Ground working position. The Ground IFR traffic could be handled completely by the digital ATCO to allow the human ATCO to focus more on the Tower side and, if present, VFR traffic.

Additionally, a combination of DM3 with DM4 – distribution by task – may be feasible. The latter method was also positively perceived by the VPs especially for simple tasks. For example, the handover task when reaching the border of the AOR could be performed by the digital ATCO even if this area of the airport is under human control. In this case, it is imaginable that the control would not be delegated to the digital ATCO explicitly but after reaching a certain point the digital ATCO would instruct the flight to contact the next responsible AOR and handover the control.

It should be noted, that the distribution methods DM3 and DM4 are the ones most similar to the automation condition of the HITL study that was performed before the semi-structured interview. As a result, there might be a bias to favour one of these methods. On the other hand, most VPs wished that the digital ATCO should control only more limited areas or tasks than experienced in the HITL study, showing that they did not prefer exactly the previously used methods.

As best fitting intervention method, IM4 – direct intervention with implicit delegation and explicit re-delegation – received the highest number of agreements. The VPs prefer a method with the opportunity to modify a flight directly but also the clear switch of control to the human ATCO who has to delegate the flight back to the digital ATCO explicitly. IM3 – direct intervention with no delegation – was also evaluated favourably by four VPs, as it allows very fast modifications to flights and no further delegation action is needed. However, the advantage of fast interactions with the flight and less delegation actions for the human comes with the disadvantage that the digital ATCO might implement conflicting actions for the flight at the same time, as the control is not delegated. As IM3 was used in the HITL study, some VPs might have experienced such a situation and were possibly influenced in their selection of the preferred intervention method. The authors decided against intervention method IM3 to ensure a clear allocation of the flight to either the human or the digital ATCO. Three VPs proposed IM5 as additional method which is similar to IM4 but with an implicit re-delegation of the flight back to the digital ATCO after a certain time span of no human intervention to this flight. This intends to simplify the delegation process. IM5 was not presented to the VPs, as it was proposed by VPs during the study. It is possible, that more VPs would have selected it, if it would have been discussed with them. Furthermore, the intervention methods were presented to the VPs after the distribution methods. The VPs might have had their favoured distribution method in mind while discussing the intervention methods. Therefore, these discussions might not have been fully independent from the distribution methods.

To connect the positive aspects of IM4 and IM5, the authors further propose IM6, a combination of both methods (Figure 12): The human ATCO can directly modify a flight and with this action

the control is delegated to the human ATCO. Like in IM5, the control of the flight is by default re-delegated to the digital ATCO implicitly a certain time span after its last modification. This ensures that the human ATCO cannot forget to re-delegate the control. Additionally, the human ATCO gets the option to mark a flight to stay under their control until explicitly re-delegating to the digital ATCO, like in IM4. Therefore, it is ensured that a flight is not re-delegated to the digital ATCO if the human ATCO desires differently. This might be especially important in emergency situations. As IM6 combines the advantages of all intervention methods to which the VPs agreed, it is selected as intervention method for future work.

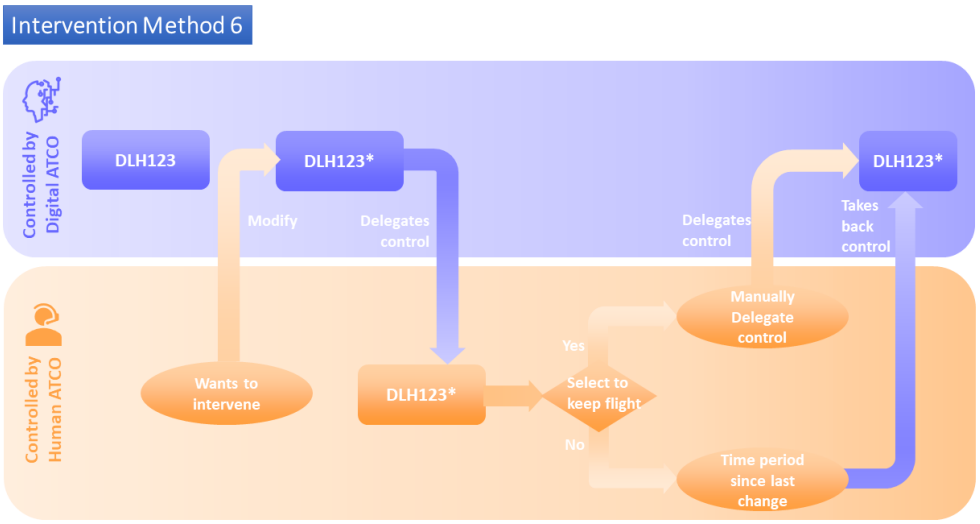


Figure 12 – Schematic illustration of IM6. Created based on feedback from the evaluations. It combines the advantages of the most agreed intervention methods and allows the human ATCO to specify whether a flight should stay under their control until it is explicitly re-delegated. Otherwise, it is implicitly re-delegated after a certain amount of time.

6. Outlook

Evaluating and selecting the methods for the human-machine-teaming concept for apron and ground controller working positions was only an early step in the development of the system. The methods are high-level proposals with enough details to enable ATCOs to understand and assess them. Now, that the most promising methods of task distribution and intervention are selected, they need to be further enhanced and finalised to a full concept. That means, interactions need to be described in more detail, use-cases need to be drawn up and non-nominal situations need to be considered. Furthermore, the user interface needs to be designed in such a way, that the human ATCO is able to supervise the digital ATCO properly, while still performing their own tasks. This is very important, as even the best human-machine-teaming concept will not be accepted if the human user cannot distinguish which tasks lie with them and which will be handled by the automation. Trust in the automation is also a very important topic that needs to be considered when developing the detailed human-machine-teaming concept and especially the user interface.

The selected methods could be compared in more detail to other human-machine-teaming concepts from research. For example, the DLR Project LOKI, dealing with digital en-route ATCOs, uses a concept where the distribution is done on a per-flight basis [18]. This is most similar to DM1 of this work, which was the least preferred distribution method in this evaluation. Analysing the reasons for the different preferences of ATCOs that participated in different evaluations for different ATC domains might bring additional insights and help to further refine the concepts.

The legal and ethical implications of responsibility and liability remain unresolved. Who has the final liability in case the digital ATCO makes a mistake? Is it the human ATCO who had to supervise the digital ATCO, or is it the vendor or the customer (airport or ANSP)? This debate has persisted

since the introduction of automated systems, however a conclusion needs to be found before such a system can be used operationally.
After the conceptual work is completed, DLR will enhance its prototypical SMAN AutoTraMICS with the selected human-machine-teaming concept and validate it in HITL simulations with ATCOs in 2027. Other studies could examine, if the concept could be applied to other airports with different conditions to analyse the transferability of the concept and whether the basic parameters that were determined to select areas under control of the human and digital ATCO can be applied generally or if they are specific for the topology used in this work.

7. Contact Author Email Address

Lennard.Noehren@DLR.de

8. Copyright Statement

The authors confirm that they, and/or their company or organization, hold copyright on all of the original material included in this paper. The authors also confirm that they have obtained permission, from the copyright holder of any third party material included in this paper, to publish it as part of their paper. The authors confirm that they give permission, or have obtained permission from the copyright holder of this paper, for the publication and distribution of this paper as part of the ICAS proceedings or as individual off-prints from the proceedings.

References

[1] EUROCONTROL. Eurocontrol performance review report (prr) 2025. https://www.eurocontrol.int/publication/performance-review-report-prr-2025.

[2] EUROCONTROL. Eurocontrol think paper #19 - atc mobility and capacity shortfalls. https://www.eurocontrol.int/publication/eurocontrol-think-paper-19-atc-mobility-and-capacity-shortfalls, 19.12.2022.

[3] IFATCA. Atco shortage: The perfect storm. https://ifatca.org/article/atco-shortage-the-perfect-storm/, 05.11.2025.

[4] EUROCONTROL. Eurocontrol forecast update 2025-2031. https://www.eurocontrol.int/sites/default/files/2025-10/eurocontrol-seven-year-forecast-2025-2031-october-2025.pdf.

[5] Mica R Endsley. Automation and situation awareness. In *Automation and human performance*, pages 163–181. CRC Press, 2018.

[6] SESAR Joint Undertaking. *European ATM master plan: Making Europe the most efficient and environmentally friendly sky to fly in the world. 2025 Edition*. Publications Office of the European Union, Luxembourg, 2025 edition edition, 2025.

[7] Ingrid Gerdes, Mohsan Jameel, Robert Hunger, Lothar Christoffels, and Hejar Gürlük. The automation evolves: Concept for a highly automated controller working position. In *33rd Congress of the International Council of the Aeronautical Sciences, ICAS 2022*. ICAS, 2022.

[8] ICAO. Icao advanced surface movement control and guidance systems (a-smgcs) manual. doc 9830 an/452, 2004.

[9] Raja Parasuraman, Thomas B Sheridan, and Christopher D Wickens. A model for types and levels of human interaction with automation. *IEEE Transactions on systems, man, and cybernetics-Part A: Systems and Humans*, 30(3):286–297, 2000.

[10] Erik Hollnagel and David D Woods. *Joint cognitive systems: Foundations of cognitive systems engineering*. CRC press, 2005.

[11] ENAC, TU Delft, Deep Blue, ADP, EUROCONTROL. *ASTAIR D1.4 Concept outline*. SESAR Joint Undertaking, 2025.

[12] Jérémie Garcia, Vincent Peyruqueou, Dong-Bach Vo, Alexandre Battut, and Mathieu Cousy. Supporting adaptive supervision and control of airport ground operation. In *AutomationXP25: Hybrid Automation Experiences*, 2025.

[13] Deep Blue, ENAC, TU Delft. *DES HE SESAR ASTAIR EXPLORATORY RESEARCH REPORT*. SESAR Joint Undertaking, 2025.

[14] Laurie Marsman, Shiva Nischal Lingam, Bart Klein Obbink, Jeanine Vlasblom, Rolf Zon, and Maykel van Miltenburg. Controller adaptive digital assistant (coda): Interim conclusions on the development of a new

atc system. In *International Conference on Intelligent Human Computer Interaction*, pages 254–260. Springer, 2024.

[15] Silvia Torsi, Stefano Bonelli, Anna Giulia Vicario, Alfonso Levantesi, and Hossein Mapar. Cognitive resilience and human-ai teaming in air traffic control, 2025.

[16] Christophe Hurter, Alexandre Veyrie, Sara Kebir, Guillaume Truong, Stefano Bonelli, Gianluca Borghini, Pietro Aricò, Fabio Babiloni, Marc Baumgartner, Juan Alberto Besada, et al. Toward a neurophysiological approach to assess optimal human-machine teaming in the critical environment of air traffic control. In *International Conference on Human-Computer Interaction*, pages 181–199. Springer, 2025.

[17] G de Rooij, C Borst, MM Van Paassen, and M Mulder. Flight allocation in shared human-automation en-route air traffic control. In *21st International Symposium on Aviation Psychology*, page 172, 2021.

[18] Robert Hunger and Sabine Theis. Importance of delegation and redelegation in human-autonomy-teamed air traffic control. In *International Conference on Human-Computer Interaction*, pages 312–322. Springer, 2025.

[19] Ingrid Gerdes, Mohsan Jameel, Leo J Materne, and Carmen Bruder. Synergies in the skies: Situation awareness and shared mental model in digital-human air traffic control teams. *Aerospace*, 12(6):472, 2025.

[20] Lukas Tyburzy, Justus Renkhoff, Mohsan Jameel, and Carmen Bruder. User centered interface design for human autonomy teaming in air traffic control: A case study. In *International Conference on Human-Computer Interaction*, pages 219–236. Springer, 2025.

[21] Meilin Schaper, Hilke Boumann, Lennard Nöhren, Lukas Tyburzy, Kathleen Muth, and Nils Carstengerdes. Validation of the traffic management intrusion and compliance system as security-awareness-component at the controller working position. *Deutscher Luft-und Raumfahrtkongress (DLRK) 2022*, 2022.

[22] Lennard Nöhren, Meilin Schaper, and Lukas Tyburzy. Towards full atc automation for aircraft ground movement: A first step. In *2024 AIAA DATC/IEEE 43rd Digital Avionics Systems Conference*. IEEE, 2024.

[23] Meilin Schaper, Lennard Nöhren, Lukas Tyburzy, Kathleen Muth, Florian Rudolph, Olga Gluchshenko, and Maik Friedrich. Validation of an automated ground movement management system. *CEAS Aeronautocal Journal*, submitted 2026.

[24] Thomas Stefani, Mohsan Jameel, Ingrid Gerdes, Robert Hunger, Carmen Bruder, Elena Hoemann, Johann Maximilian Christensen, Akshay Anilkumar Girija, Frank Köster, Thomas Krüger, et al. Towards an operational design domain for safe human-ai teaming in the field of ai-based air traffic controller operations. In *2024 AIAA DATC/IEEE 43rd Digital Avionics Systems Conference (DASC)*, pages 1–10. IEEE, 2024.

[25] Lukas Tyburzy, Meilin Schaper, Olga Gluchshenko, Lennard Nöhren, Anna Simon, and Kathleen Muth. Operational benefits of sustainable engine-off taxi operations: Results from human-in-the-loop simulations. In *2026 International Workshop on ATM/CNS, IWAC 2026*. ENRI, submitted 2026.