Supporting Adaptive Supervision and Control of Airport Ground Operation

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Abstract

Air traffic control (ATC) relies on both human operators and automation to ensure safety and efficiency. As air traffic grows, automation is increasingly adopted. However, fully automating airport ground operations, aircraft movement between parking areas and runways, remains unfeasible due to the unpredictability of ground traffic, including aircraft delays, sick passengers or weather disruptions. In this paper, we investigate strategies to support dynamic levels of automation, introducing interfaces that enhance supervision through a domain specific graphical language and explicit automation level representations. We also introduce automation- and human-generated cross-checks to monitor critical situations and propose interaction concepts to adjust the level of automation. We conclude with future directions for enabling human operators' interventions with high levels of automation and implications for Human-AI teaming in ATC.

Keywords

Human-Automation Teaming, Shared Supervision, Airport Automation

1. Introduction

Air traffic control (ATC) is a complex hybrid system that includes humans and automations [9] to organize the movements of aircraft in the air or on the airport with two main objectives: safety and capacity. Automation is widely adopted in international air transport research programs to address increasing air traffic [2]. The ASTAIR project focuses on increasing automation on airport ground operations, *i.e.* motions from aircraft between their parking areas and the runways, to enhance predictability, efficiency, and environmental performance [8]. While automation can improve decision-making and traffic flow, it also presents challenges for both autonomous systems—responsible for making appropriate decisions—and human operators, who must maintain situational awareness to intervene when necessary [1,6,13]. The unpredictable nature of airport ground traffic and operations makes full automation difficult, as it requires human expertise to assess situations and define appropriate automation strategies [4,7]. Factors such as unexpected aircraft delays, varying weather conditions, and dynamic human-operated vehicle movements further complicate automation efforts.

Our goal is to design a seamless Human-Automation Teaming system for managing aircraft ground taxiing across major European airports. This requires integrating multiple automation levels, from decision support to full automation (level 1, 2 and 3 of EASA's definition of levels of automation) [7]. Although automation offers potential improvements in safety, efficiency, and scalability, research remains limited on how to design highly automated interactive systems that effectively support human control [4,5].

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This paper presents findings from design workshops with professional stakeholders to identify relevant scenarios, tasks, and reachable automation levels. We propose interaction concepts to support human supervision and control of an automated airport, including a shared visual language to enhance human-automation communication and automated cross-checks to monitor critical situations. Finally, we outline future work to refine human control strategies and discuss possible broader implications of our findings on Human-Automation Teaming.

2. Background on Ground Airport Operations and Envisioned Automation

Ground controllers at airports manage aircraft movement on taxiways and runways, ensuring safe and efficient operations [10]. They coordinate takeoffs, landings, and taxiing while communicating with pilots to provide routing and clearance instructions. Their role is essential for maintaining smooth airport traffic flow, preventing collisions and handling emergencies when necessary. Within the ASTAIR project we explore how increasing automation could enhance the predictability of airport turnaround operations by autonomously planning conflict-free trajectories for departures and arrivals and managing vehicle movements. However, high levels of automation (2 and 3) into daily airport operations presents significant challenges, as full automation may not always be feasible. Ensuring effective collaboration between human controllers and automated systems remains a critical consideration.

To address these challenges, we identified and explored 8 scenarios with major European airports stakeholders. They cover day-to-day airport turnaround operations and include towed departures, re-scheduled operations, arrivals while the parking is still occupied, changes of runway mode of operation, remote holding before departure, arrivals with technical issues, high level tuning of automation’s strategies and automation failures. The figure below illustrates one of the scenarios that helped us design interactive tools that take advantage of operators’ expertise for controlling and engaging with the automation at diverse levels.

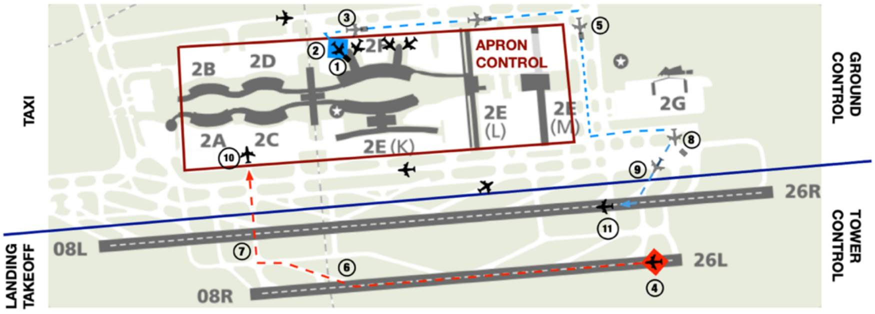

Figure 1: Towed departure scenario: (1) The tug couples to the departing aircraft (blue). (2) Pushback clearance is given by ground control and perform by the autonomous tug and supervised by ground handlers. (3) The tug tows the aircraft on the taxiways. (4) An aircraft (red) is about to land on the runway. (5) The automation requests the tug to slow down to accommodate the landing aircraft and avoid disrupting the traffic flow. (6) The arriving aircraft exits the runaway. (7) Since, the departing aircraft has been slowed down by the automation, the arriving aircraft can cross the departure runway without stopping. (8) The departing aircraft has started the engines and the tug has been released. (9) The pilot contacts tower control to queue for takeoff. (10) The arriving aircraft taxis to the parking stand. (11) The departing aircraft takes off.

In the scenario presented in Figure 1, the degree of automation varies according to task.. For instance, in (5), the ground controller gives authority to the automation to drive the tug towing the aircraft to the runway. The controller can monitor the automation providing intersection crossing clearances and taxiing speeds. Controlling and slowing down the tug is level 3 of EASA’s definition of levels of automation [7]: controllers can override all the decisions and the actions that the AI performs. In (8), the automation notifies the controller that the departing aircraft engines need to be started. The controller then issues a start engine clearance to the pilot. This is level 2 automation. Different levels of automation allow more efficient ground operations while ensuring humans’ engagement with the system.

3. Interactions for Ground Supervision and Automation Control

Following our workshops, we iteratively designed and implemented new interfaces and interaction to help ground controllers to collaborate with automation in supervising and controlling aircraft operations. The application consists of two primary components: the global supervision area that provides an overview of operations (Figure 2 left a-b-c) and the detailed inspection and advanced surface movement control area that provides in depth monitoring and adjustments (Figure 2 right d-e). In the next sections, we describe the key components of our functional prototypes and interaction concepts we have designed in collaboration with our participants.

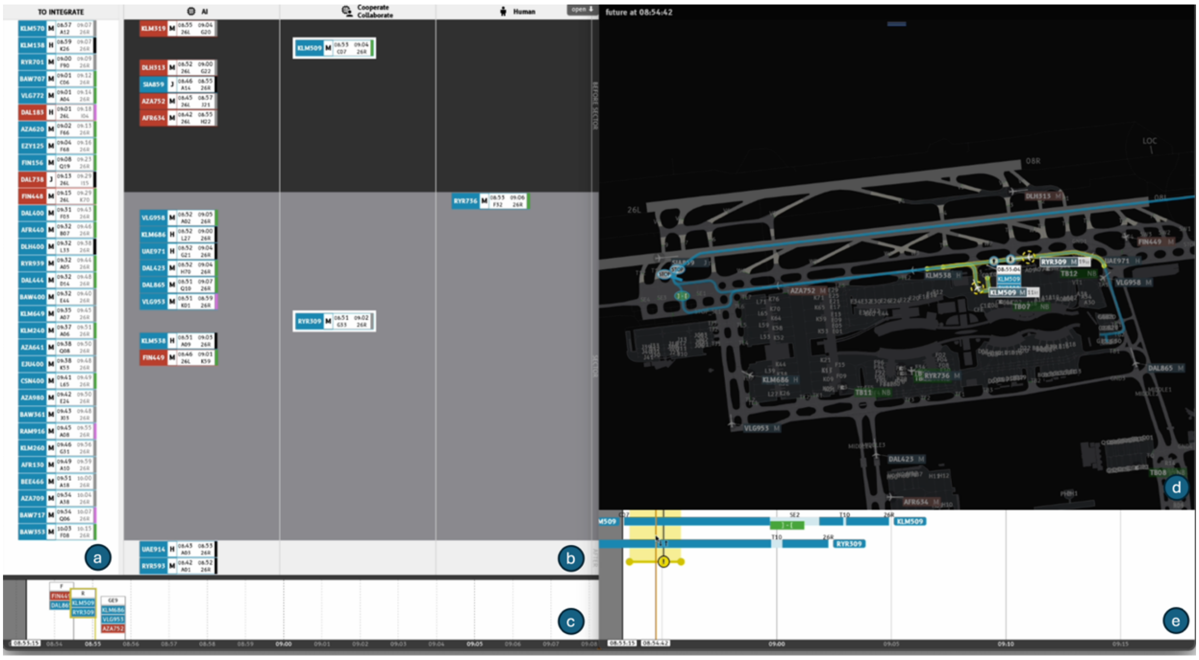

Figure 2: Supervision and Control interfaces: a) list of scheduled departing and arriving aircrafts; b) the global supervision area; c) a timeline with identified cross-checks; d) the inspection map and e) the inspection timeline.

3.1. Global Traffic Supervision

To give controllers a comprehensive overview of the aircraft statuses and automation plans such as routes, speeds and priorities. the supervision area displays all departing and arriving aircraft as interactive strips, showing their assigned departure runways or arrival parking positions (Figure 2). Controllers can monitor temporal constraints such as scheduled departure and arrival times (Figure 2.a). The automation system ensures conflict-free traffic by assigning constraints on routes and speed that prevent collisions if followed.

Ground controllers must integrate the flights, *i.e.* validate the generated plan for each aircraft (typically 5–10 minutes in advance), by dragging the strips into one of three operational columns representing different levels of human and automation authority (Figure 2.b):

- **AI-Controlled (automation level 3)**, the automation system has full authority to issue clearances (orders) and manage the aircraft independently;
- **Human-Automation Cooperation (automation level 2)**, the AI suggests a route and guides aircraft along it, but specific actions such as engine startup or supervising critical phases require human oversight or control;
- **Human-Controlled (automation level 1)**, the controller fully manages the flight, manually defining the route and handling all priorities possibly using decision support tools but with no automation-issued clearances.

Each of the column is divided into three zones that reflect the aircraft's current operational stage: **the top zone** includes aircraft waiting for departure or about to land, helping controllers anticipate upcoming movements; **the middle zone** is for aircraft taxiing on the airport that must be supervised; **the bottom zone** is for parked aircraft or aircraft with transferred authority, no longer requiring ground control intervention. Aircraft strips move vertically through these zones as their status changes, progressing from pre-flight/pre-landing, through active routing, to transferred/arrived status.

Figure 3: Main radar image for supervising moving aircrafts on the airport (Paris-Charles de Gaulle here). Blue labels correspond to departing aircrafts and red label to arriving aircrafts. Green labels represent towing vehicles.

In addition to the supervision interface, controllers also use a radar interface (Figure 3) that provides a dynamic visual representation of aircraft movements, helping them to track aircraft positions and confirm the execution of planned trajectories. To reduce cognitive load, flight labels remain minimized and semi-transparent when the controller does not yet have authority over a flight as suggested by participants. Once a controller gains authority, the relevant flight details are revealed. If the flight strip is placed in the *Human-Automation Cooperation* or *Human-Controlled* column, it becomes opaque, ensuring the information remains visually prominent.

3.2. Inspecting and Controlling automation

Before validating an automation plan for an aircraft, controllers can inspect and adjust plan details. Another view provides decision-support tools to assess spatial and temporal plan information computed by the AI to increase controllers' situational awareness. The interface consists of two main areas: The Airport Map (Figure 2.d) that displays aircraft routes and planned events (e.g., coupling to a towing tug, engine start, holding positions) and; the timeline view (Figure 2.e) that presents the same events in a chronological format. Controllers can interact with the timelines to assess aircraft's planned routes. By hovering the cursor on an aircraft track over the timelines, they can follow the selected aircraft route and compare it with the other aircraft routes on the taxiways over time. Exploring by time control allows the controllers to investigate taxiing plans and aircraft movements dynamically to improve their awareness of the airport traffic.

We also propose a domain specific graphical language (DSGL) [4], illustrated in Figure 4, which uses symbols on the aircraft routes or on the aircraft tracks in the inspection timeline view to support immediate understanding of automation's operational plans. Relevant instructions were identified during workshops with ATCOs and used to design the DSGL (Figure 4.c): "Hold Short" requests the pilot to remain stationary at a holding point, typically to give way to another aircraft; "Reduce Speed" requests the pilot to decrease their speed to a specified location; "Tug+/Tug-" specifies where a tug is requested to start or to stop tugging the plane; "Call area" instructs the pilot to call back the ATCO at a specified location; "Transfer to another frequency" instructs the pilot to change the communication radio frequency for another control area, for example from ground to tower control; "Priorities", informs pilots about the crossing order at a specified intersection.

These graphical instructions provide an intelligible representation of the automation's routing plans. Workshop participants emphasized the importance of the DSGL as it provides immediate understanding of the plan. They appreciated the use of the same language over the aircraft trajectories (Figure 4.a) and the corresponding flight time tracks (Figure 4.c).

Controllers can adjust priorities and impose new constraints on the automation within the inspection interface. They can also modify routes through direct manipulation as with previous projects on interactive ground radar images [3]. Dragging symbols over aircraft routes, time tracks, or by using a contextual menu over a route specific location amends taxiing regulations (Figure 4), resulting in a new computed plan from the automation.

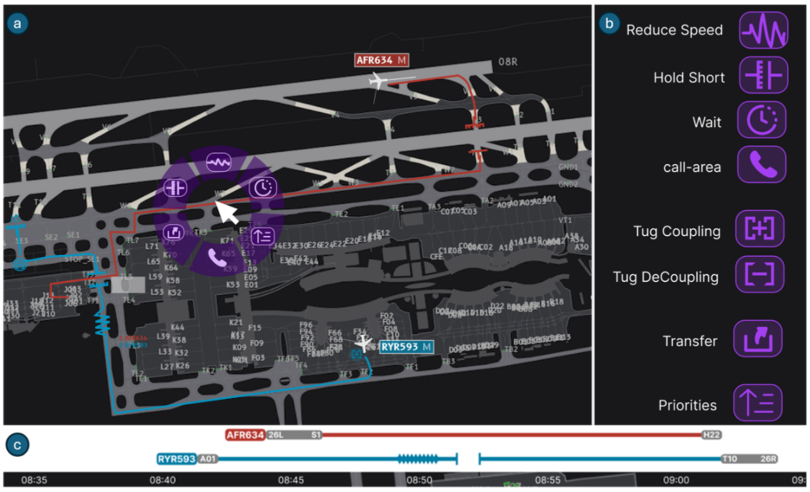

Figure 4: Prototypes of the detailed inspection and advanced surface movement control interface. The domain specific graphical language is displayed over the aircraft trajectories (a) and the timeline (c) to represent operational events such as coupling to uncoupling from a towing tug, stopping to a specific point or reducing speed to enable a priority (b).

3.3. Human and Automation Cross-Checking of challenging situations

We define the concept of “cross-check” as a representation of a specific situation which requires both human controllers’ and automations’ close attention. It involves one or more aircraft, their spatial location in a specified timespan, and the regulations put in place by the automation or the controller. A cross-check can be generated by the automation, based on predefined distance thresholds, regulatory detections or a specific routing strategy (e.g. slowing an aircraft down or prioritizing another at an intersection). Controllers can also create them manually, because they want to anticipate a situation potentially leading to a conflict (e.g. because a pilot is new to the airport, or because a routing strategy is unconventional).

Cross-check representations in the different views serve as a human-automation medium to communicate uncertainty (Figure 5). Cross-checks can be fine-tuned to adjust temporal and spatial positions on both inspection and supervision timelines (Figure 5.B & Figure 5.C) and on the inspection map (Figure 5.A) by direct manipulation. All cross-check representations are synchronized in real-time and convey specific contextual information based on the view they are displayed on (e.g. cross-checks on the inspection timeline are related with the routing regulations of involved aircrafts).

When a cross-check is initiated, the involved aircraft strips are shifted to the “Human-Automation Cooperation” column in the supervision area so the controllers can handle the cross-checks, and the tags attached to the involved aircraft are highlighted to catch controllers’ attention.

4. Discussion and perspectives

The design of automation systems must account for varying levels of human's engagement to avoid automation complacency and out-of-the-loop situations [15]. One participant noted that *"task validation reinforces commitment and skill maintenance"*, which aligns with our approach of requiring operator validation before automation assumes control.

In our work, we explored how to combine several levels of automation to supervise and control the airport. Our system explicitly distinguishes between human-controlled (level 1), teaming (level 2), and fully automated (level 3) modes, helping controllers to maintain oversight and to intervene when necessary. This aligns with Kaber et al.'s work [12], who argued that adaptive automation, where control shifts dynamically between human and AI, can optimize both performance and cognitive workload.

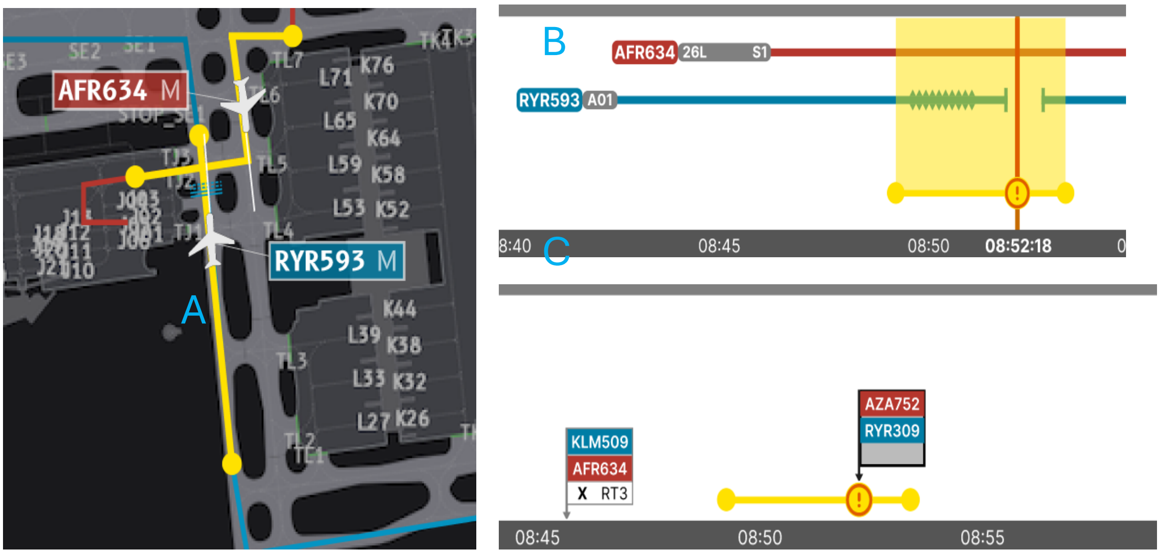

Figure 5: Crosschecks interactive representation on the inspection map (A), the inspection timeline (B) and the supervision timeline (C).

Our findings also highlight the importance of a **shared representation between human operators and automation** to ensure effective coordination in airport automation. For instance, several participants appreciated the ability to understand the automation's future decisions for each situation through the DSGL over the map and the interaction concepts. This is consistent with Johnson et al.'s previous work, which shows that shared representations enhance human-robot teamwork by improving situational awareness and reducing misunderstandings [11]. Such shared representations also enhance automation support while keeping controllers' established practices, which is in line with the principles of "human-centered automation" proposed by Sheridan [14].

Our workshops with ground handlers and air traffic controllers highlighted the importance of human expertise in resolving complex situations, such as handling novice pilots or extreme weather conditions, that automation alone may not fully understand. Our current direction is to study how to support controllers with adjusting the automation to specific and localized operational events inherent to airport control. We will leverage our domain specific graphical language to allow controllers to adjust the automation. In particular, we aim at leveraging human operators' unique expertise on airport activities based on experience to guide the automation to achieve better performance.

Future work will also focus on conducting evaluation of the systems and tools presented in this paper in realistic simulations to assess not only their efficiency and effectiveness but also the impact of interacting with different levels of automation, on the supervision and control of highly automated airports.

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