

D3.1 Specification of interaction for gradual automation programming from ATC supervision tool

Deliverable ID:	D3.1
Project acronym:	ASTAIR
Grant:	101114684
Call:	HORIZON-SESAR-2022-DES-ER-01
Topic:	HORIZON-SESAR-2022-DES-ER-01-WA1-1
Consortium coordinator:	Ecole Nationale de L'Aviation Civile (ENAC)
Edition date:	22 May 2025
Edition:	01.01
Status:	Official
Classification:	PU

Abstract

This deliverable presents the results of workshops with ground controllers, ground handlers as well as with the consortium members and the stakeholder consultation group for identifying and narrowing the first set of expectations of the project. In particular we identified use cases with several automation levels that will be explored in WP2 (Support algorithms) and WP3 (Automation Supervision & Control HMI design and development).

Authoring & approval

Author(s) of the document

Organisation name	Date
ENAC	10/03/2025

Reviewed by

Organisation name	Date
ADP	20/03/2025

Approved for submission to the SESAR 3 JU by¹

Organisation name	Date
TUD	21/03/2025
ADP	21/03/2025
Deep Blue	21/03/2025
Eurocontrol	21/03/2025
ENAC	21/03/2025

Rejected by²

Organisation name	Date

Document history

Edition	Date	Status	Company Author	Justification
00.01	31/01/2025	Initial version	ENAC	The table of content and the overall setup
00.02	12/03/2025	Intermediate version	ENAC	Draft of the deliverable is written and provided for internal review
01.00	21/03/2025	Final version	ENAC	The final version with all comments of the project participants addressed

¹ Representatives of all the beneficiaries involved in the project

² Representatives of the beneficiaries involved in the project

01.01	22/05/2025	Final version	ENAC	Corrections after S3JU reviews (D1.3 reference in §1.2 and video links in §5)
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ASTAIR

AUTO-STEER TAXI AT AIRPORT

ASTAIR

This document is part of a project that has received funding from the SESAR 3 Joint Undertaking under grant agreement No 101114684 under European Union's Horizon Europe research and innovation programme.



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Executive Summary

The goal of the ASTAIR project is to design a seamless partnership between Human and Artificial Intelligence (AI) to manage and perform engine-off and conventional airport surface movement operations at major European airports. ASTAIR original approach to automation is to consider an integrated airport system instead of many separate sub-systems, analyse the level of autonomy an AI system could take on tasks and to make the automation controllable by humans at different levels.

With the introduction of high-level automation for airport surface movement operations, the role of operators and airport operation procedures will significantly change. The key to optimize the overall performance of the collaboration between humans and AI is to adapt intelligent systems to the operators' modus operandi. This will ensure logical consistency across manual and automated control and reduce the cognitive distance between levels of automation by mapping system functions to goals and mental model of operators. In ASTAIR, we will propose interactive tools and adaptative AI algorithms that take advantage of operators' expertise for controlling and engaging with the automation at diverse levels.

This document describes the Human-Machine Interface (HMI) for supervising and controlling ground movement on highly automated airports. The HMI consists in 1) an overview of the departing and arriving aircraft and their status (level of automation and progression of the operations as well as potential situation to monitor in a timeline; 2) a map and a timeline enabling understanding, exploration and modification of planned movements both by AI (D.2.1) and human operators; 3) a set of interaction to override the plans from the AI while aircrafts are moving. The HMIs and interactions can be used in conjunction with an Advanced Surface Management Guidance and Control System (A-SMGCS) tool presenting the tugs and aircraft positions on the airport map along with the planned trajectories.

This deliverable consists in the description of interaction techniques i.e. the sequence of actions and reactions between the graphical representation and the inputs from the end-user. The specifications of the interactions come in several forms, included in or accompanying this document: drawings, scenarios, and videos. The interaction concepts have been designed and discussed with several stakeholders with ground control expertise.

1.1 Purpose and scope of this document

This document describes the Human-Machine Interface (HMI) to supervise and control the ground traffic. Interfaces and interaction concepts are described for the Paris Charles de Gaulle Platform but is applicable to many large airports implementing Airport Collaborative Decision Making (A-CDM) having dedicated data sharing infrastructure that seems mandatory to implement the ASTAIR envisioned Conception of Operation.

1.2 Background and related documents

This deliverable takes as input the research reported in deliverable D1.3 "Initial concept outline" which describes the impacts of the ASTAIR concept on current ground operations and the potential possible improvements to ground operations. Furthermore, the deliverable builds upon the deliverable D.1.2 "Workshops report" which highlights the requirements of ground operations in large European

airports and provides relevant ground operation use cases with different levels of automation in accordance with EASA’s Artificial Intelligence Roadmap 2.0. The interaction concepts will be evaluated in the final evaluation of the ASTAIR solution and the results will be published in the deliverable D.5.2 “Exploratory Research Report”.

1.3 Levels of automation definition

To present the reachable levels of automation we identified in our activities and the levels the ASTAIR project will try to achieve, we decided to use the levels defined in the ARTIFICIAL INTELLIGENCE ROADMAP 2.0 report [2] from EASA. The report defines three levels of Automation according to the roles of Humans and AI. Figure 1 describes the roles of Humans and AI for these three levels.

Level 1 AI: assistance to human	Level 2 AI: human-AI teaming	Level 3 AI: advanced automation
• Level 1A: Human augmentation • Level 1B: Human cognitive assistance in decision-making and action selection	• Level 2A: Human and AI-based system cooperation • Level 2B: Human and AI-based system collaboration	• Level 3A: The AI-based system performs decisions and actions that are overridable by the human. • Level 3B: The AI-based system performs non-overridable decisions and actions (e.g. to support safety upon loss of human oversight).

Figure 1: EASA levels of automation defined in [2].

The levels 2A and 2B are different because of the two terms cooperation and collaboration that are defined as follows:

Cooperation is a process in which the AI-based system works to help the end user accomplish their own objective and goal. The AI-based system will work according to a predefined task allocation pattern with informative feedback on the decision and/or action implementation. Cooperation does not imply a shared vision between the end user and the AI-based system. Communication is not a paramount capability for cooperation.

Collaboration is a process in which the human and the AI-based system work together and jointly to achieve a common goal (or work individually on a defined goal) and solve a problem through co-constructive approach. Collaboration implies the capability to share situational awareness and to readjust strategies and task allocation in real time. Communication is paramount to share valuable information needed to achieve the goal, to share ideas and expectations.

In the remainder of this document, we will describe the levels of automation according to these levels but we will simply and use only level 1, 2 or 3. For level 3, it is implicitly level 3A that is used since humans will be able to override decisions and actions at any time.

1.4 Structure of the document

Section 2 describes introduces the methodology followed to design the HMI and the interactions.

Section 3 describes the HMI architecture and its main components.

Section 4 illustrates the envisioned use of this HMI through several scenarios building on the project's use case.

Section 5 describes the status of the video associated and the status of the HMIs presented in this deliverable. It also presents how the results will be used within the ASTAIR project.

2 Methodology

A major concern while designing interactive systems is to reach a suitable level of usability for end-users. Usability is the “extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use” [3]. Human-Centered Design (HCD) is concerned with the design of such usable systems. HCD is “an approach to system design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques”. In particular, the design is based upon an explicit understanding of users, tasks and environments, and is driven and refined by user-centered evaluation. Given that the levels of automation envisioned within the ASTAIR project range from level 1B to level 3A we expect a paradigm shift in Air Traffic Controllers (ATCOs) roles from controller to become supervisors and partners of an AI. We thus conducted several user centered design activities simulating high levels of automation to collect feedback on such contextual changes and improve our designs. Figure 2 describes the user centered activities we have conducted.

The first step consisted in building upon the requirements elicited during the workshops (D.1.2) and specific guidelines identified in the State of the Art (D.1.1). We then conducted several internal design sessions which resulted in concept mock-ups which in turn were partially implemented, including the supervision interface with a list of strips for all aircrafts presenting their expected level of automation and when human input was required for specific actions. We evaluated these designs with several ATCOs. The results helped us identify main challenges with our design regarding the ability to understand the AI plans including the identification of conflicts and planned resolution.

The second step consisted in investigating these specific challenges by conducting several internal design sessions which resulted in concept mock-ups first, and the partial implementation of these concepts next. These concepts include visual representations of operational events over the computed trajectory and cross-checks, situations in which AI and Human need to monitor a specific situation. We prototyped the interaction with a realistic simulation enabling to experiment some of the interactions in a realistic context. We then conducted two design workshops with ATCOs that allowed us to understand the benefits and challenges they may face with such concepts. These workshops resulted in improved design and interaction techniques for understanding operations on a highly automated airport and interaction to control the AI with suggestions to use planning where different strategies could be used to resolve specific situations in different time frames.

In the third step, we conducted several internal design sessions to design and implement working prototypes of the HMI and interactions presented in this report. We conducted a validation session using realistic simulations with an experienced ATCO in the ENAC facilities. Our goals were not only to identify the situational awareness elements contributing to the understanding automation levels and AI decisions and actions, but also to ensure that the interaction concepts provide enough control of AI plans in different time frames to cope with the AI’s inability to deal with unpredicted situations such as arrival or departure delays. Based on the results of the assessment, another internal design iteration was performed.

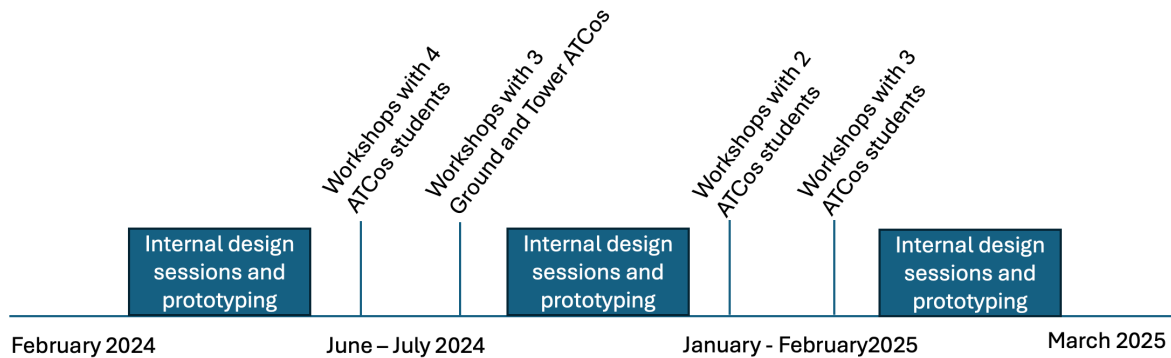


Figure 2: timeline of the design activities and the participants.

The following content in this deliverable is the current design outcomes. All the HMI design concepts will be presented again to ATCos and various stakeholders during the final evaluation activities in the ACHIL platform at ENAC (WP5).

3 HMI architecture and components

This section introduces all the Human-Machine Interfaces designed for ASTAIR. First, we present an overview of the interfaces and then present each component in more detail.

3.1 Overview

For ASTAIR, we designed a new application and dedicated interactions 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 and the detailed inspection and advanced surface movement control area that provides in depth monitoring and adjustments (Figure 3 right). This application is meant to be used in conjunction with an A-SMGCS radar image which allows the spatial monitoring of all the vehicles on the apron and the taxiways including towing vehicles and aircraft, similarly to the tool used by ground ATCOs (Figure 3 left). The A-SMGCS presents real-time data and the current situation on the platform while the new application allows to monitor current and planned activities.

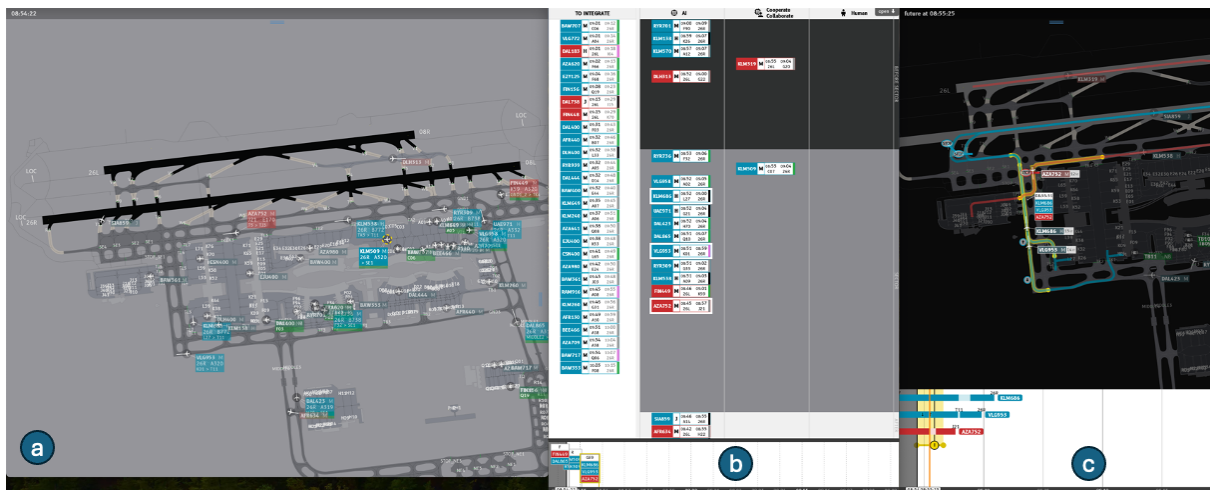


Figure 3: (a) A-SMGCS interface presenting real-time information about the traffic on the platform. (b) Global supervision interface with all scheduled and moving aircraft. (c) The inspection interface with details on selected aircraft routes and events.

The HMIs are connected to other systems such as 1) the A-CDM which specifies the taxiing technique chosen with estimated time of departure or arrival, 2) the allocation and path planning algorithms to compute tug allocation and conflict free routes for all ground vehicles as described in D.2.1.

The HMIs are also synchronized to allow more efficient operations. The supervisor can select a vehicle on the A-SMGCS interface, highlight and locate the corresponding strip on the supervision HMI. Conversely, they can select a strip on the supervision HMI to highlight and locate the corresponding mobile unit on the real-time A-SMGCS interface. Selections are synchronized between the global supervision HMI and the inspection HMI, allowing the ATCO to obtain a relatively precise understanding of taxiing operations. By selecting an aircraft or other elements on the supervision HMI, supervisors can observe the corresponding results on the inspection HMI. However, selections on

these two HMIs do not affect the A-SMGCS HMI, which exclusively displays the current positions of mobile units. This distinction enables the ATCO to start integrating an upcoming flight on the right screen, temporarily interrupt their task to monitor/control another flight as it taxis by selecting it on the left screen and then resume work on the upcoming flight without modifying the previous selection(s). We decided to use touch or pen-based input to support direct engagement and actions with both touchscreen displays as mouse pointing across screens would decrease selection performance.

3.2 Global traffic supervision interface

The global supervision interface, visible in Figure 4, allows the ATCO to monitor all flights. It provides a view of aircraft still at the gates anticipating taxi for departures and those approaching the airport from arrivals (Figure 4.a), those that have been integrated and about to move (Figure 4. b), those currently taxiing (Figure 4. c) as well as those that were transferred to the runway ATCO or the parkings (Figure 4.d). It also presents a sorted list of situations requiring attention in the timeline at the bottom area of the HMI (Figure 4.e). We call them cross-checks. A Cross-check is either automatically detected with distance threshold or manually added by the user while integrating the flight. There are two types of cross-checks : intersections and catch-up (even though catch should not occur under speed control).

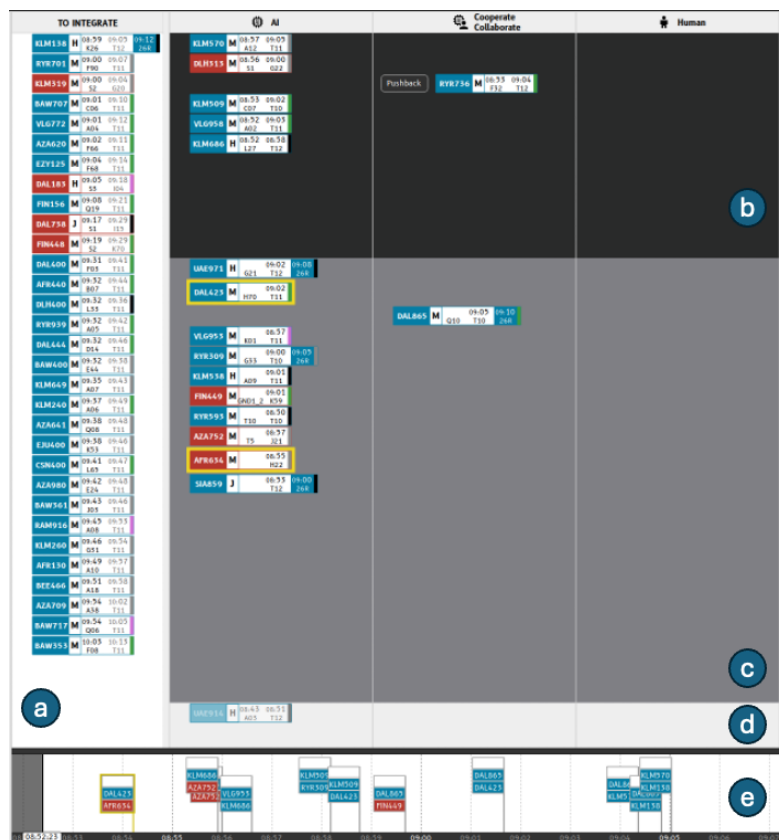


Figure 4: Global supervision Interface including : a) flights to be integrated b) pre-departure or pre-arrival aircraft that have been integrated; c) taxiing aircraft d) recently transferred aircraft (tower or parking) e) cross-check situations that will require more ATCO attention.

On this interface, one or several flights can be selected. To add a flight to the current selection, the supervisor simply clicks on the colored rectangle behind the callsign. A yellow frame appears around all selected strips. Clicking again removes the strip from the selection. A double-click on the background of the window deselects all selected strips.

3.2.1 List of planned flights

Figure 5 details the list of strips that represents all upcoming flights sorted by their expected taxi start time within the ATCO's sector of responsibility. This is the TOBT (Target Off Block Time) for departures or a calculated time at the taxiway entry point from the vacated runway for arrivals. Our design draws inspiration from AMAN and DMAN tools used by ATCOs in their current practices. These strips are called *to be integrated*, because ATCOs must review the plans for these aircraft before adding them to the ones that will be controlled either by the automation, the ATCOs or both.

TO INTEGRATE				
RYR593	M	08:42 A01	08:50 T10	
UAE914	H	08:43 A03	08:51 T12	
AFR634	M	08:46 S1	08:55 H22	
SIA859	J	08:46 A14	08:53 T12	09:00 26R
FIN449	M	08:50 S1	09:01 K59	
AZA752	M	08:50 S2	08:57 J21	
KLM538	H	08:51 A09	09:01 T11	
RYR309	M	08:51 G33	09:00 T10	09:05 26R
VLG953	M	08:51 K01	08:57 T11	
DAL865	M	08:51 Q10	09:05 T10	09:10 26R
DAL423	M	08:52 H70	09:02 T11	
UAE971	H	08:52 G21	09:02 T12	09:08 26R
KLM686	H	08:52 L27	08:58 T12	
VLG958	M	08:52 A02	09:03 T11	
KLM509	M	08:53 C07	09:02 T10	
RYR736	M	08:53 F32	09:04 T12	
DLH313	M	08:56 S1	09:00 G22	

Figure 5: list of planned aircraft to be integrated temporally sorted .

The top strip represents the forthcoming aircraft scheduled for taxiing in the ATCO's sector. The ATCO must be aware of this flight to incorporate it into traffic planning. Based on the workshops results, we decided to force the review of the automation plans for each aircraft before their inclusion to the planned operations. This is meant to involve the ATCO in the task and ensure that he or she builds adequate situation awareness of the traffic. However, the ATCO remains free to integrate flights earlier or later than the current time. The strips are color-coded: blue for departures and red for arrivals, consistent with existing tools used at CDG airport. The flight callsign and aircraft category (Light, Medium, Heavy, Jumbo) are displayed on the left side of the strips. To grab and move a strip, the supervisor must press on the callsign, hold, and then drag the strip using the pen or touch.



Figure 6: Strips representing aircraft: left) departure flight planned to taxi at 08:46 with a CTOT; center) arrival flight planned to taxi at 08:50 and right) selected arrival planned to taxi at 8:56.

All strips share a similar content organization. In the center, the first column indicates the taxi start time and position within the sector, while the second column shows the taxi end time and position. These values are computed according to the type of flight:

- **Departure:** The parking stand name and TOBT and expected time at the runway entry point.
- **Arrival:** The runway exit name and AI-calculated time based on ETA (Estimated Time of Arrival) and TIBT to the gate.

At CDG, landings occur on outer runways, while takeoffs take place on inner runways. Consequently, arriving aircraft must wait for clearance from the local controller (LOC) to cross the departure runway before being transferred to the ground controller. Since this clearance is given manually, there is an approximation in the AI's calculation of the taxi start time. In the prototype, the displayed information includes the holding point name at the departure runway entrance and the AI-calculated time.

For departures with a regulated slot provided by the Network Manager, an additional column on the right displays the assigned takeoff runway and CTOT (Calculated Take Off Time) on a blue background. The Taxiing Mode of Operation (TMO) from A-CDM is represented by a thin colored band on the right tip of the strip, following the AEON project color code: green for tugs, purple for electric engines, gray for Single Engine Taxiing (SET), and black for Full Engine Taxiing (FET).

3.2.2 List of integrated flights

In the central part of the supervision interface, illustrated in Figure 7, a list of strips is organized through three columns and three rows.

Level of automation columns

When integrating a flight, the supervisor assigns it an automation level by placing it in one of the three columns:

- **AI-Controlled (Level 3):** The automation system has full authority to issue clearances and manage the aircraft independently.
- **Human-Automation Cooperation (Level 2):** AI suggests a route and guides aircraft, but key actions such as engine startup or supervising critical phases require human oversight. This level also encompasses situations where the automation finds an event and ask the controller for a decision to handle the specific situation.
- **Human-Controlled (Level 1):** The controller fully manages the flight, manually defining the route and handling all clearances without AI-issued commands.

The supervisor assigns a flight's automation level by dragging and dropping the strip into the desired column. At any time, they can change this level by moving the strip between columns.

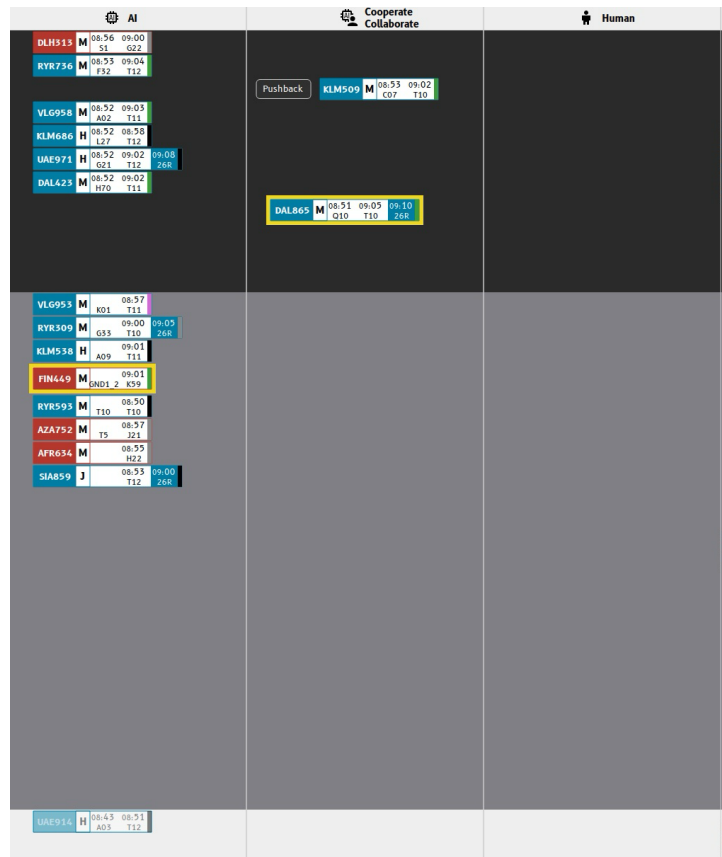


Figure 7: list of integrated flight organized horizontally by level of automation and vertically by responsibility.

Dropping or moving a strip into the left column means that the ATCO grants the automation full authority on the flight taxi from start to transfer at LOC (for departures) or to the parking stand (for arrivals). The automation determines the route, controls the speed throughout the taxi phase, and issues taxi clearances. Strips in the "AI-Controlled" column will automatically shift to "Human-Automation Cooperation" column under the following conditions that were identified during our workshops:

1. **Pushback clearance:** When an ATCO must authorize a pushback operation for departures, a "Pushback" button appears on the strip. Once clicked, the strip moves back to "AI-Controlled."
2. **Engine startup clearance:** Some airlines require manual clearance for engine startup. When needed, an "Engine" button appears on the strip. Clicking it moves the strip back to "AI-Controlled."
3. **Cross-check situations:** Once a cross-check has been set off, when two or more flights are 60 seconds away from intersection, the related strips will be linked visually. This serves as an alert for the ATCO to monitor and intervene if necessary. Thirty seconds after intersection, the strips return to "AI-Controlled."
4. **Arrival without parking:** When the automation detects that a parking will not be available for an arriving aircraft, a contextual menu will appear to enable the ATCO to chose a strategy.

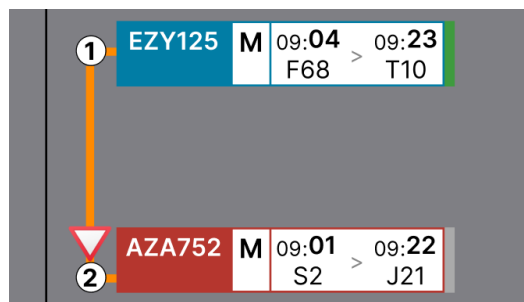


Figure 8: During the cross-check situation between EZY125 and AZA752, both strips are moved into column "Human-Automation Cooperation".

Figure 8 illustrates the strips representation during a cross-check. The strips **EZY125** and **AZA752** are placed in the central column. An orange link connects the different strips involved in the cross-check to facilitate identification, especially when multiple cross-checks are active simultaneously. The priority at the intersection between flights is indicated both by the order displayed to the left of each strip and by a "Give Way" sign positioned to the left of the strip that must yield priority.

Responsibility zones

The integrated flight list is divided into three rows to indicate sector progression. In the top row, the flight is in a sector that is not under the ATCO's responsibility yet. In the middle row, the flight is actively taxiing under the ATCO's responsibility. In the bottom row, the flight has exited the sector and is no longer under the ATCO's responsibility. In this row, the strip becomes semi-transparent before disappearing.

Flights are gradually moved through columns, the responsibility zones, using visual animations as they progress. The ATCO monitors them and provides clearances where necessary. Strips in the "AI-Controlled" column delegate taxi routing and speed instructions entirely to the automation, while those in the "Human-Controlled" column require full manual management.



Figure 9: (left) taxiing strip in the sector, (right) taxiing strip after the transfer to the LOC / lower zone

For flights that have started taxiing, the strip no longer displays the initial taxi start time (see Figure 9, left). Instead, it shows the aircraft's current position, replacing the original taxi start position.

When a flight is transferred to the next sector, its strip moves from the central row to the top of the lower row. It is gradually pushed downward as new flights are piling up in the column. Since the lower row has limited height, transferred flights quickly fade away, but they remain visible briefly to inform the ATCOs that they are no longer under their responsibility:

- **For a departing flight**, the strip is transferred to the ATCO Tower when the aircraft reaches the runway threshold. The transfer is handled automatically by the automation if the strip is in the "AI-Controlled" or "Cooperation" columns, ATCO must give the information manually to the aircraft otherwise (i.e. the strip is in the "Human" column).

- **For an arriving flight**, the strip leaves the ATCO's sector once the aircraft has reached its designated parking stand.

Transferred strips are displayed with transparency to indicate that they are no longer active under the ATCO 's management.

Time or Location Updates

As long as flights have not been integrated to the ATCO's plan, automation will adjust the global plan according to schedule changes. Once a flight/strip has been integrated to the ATCO's plan, any schedule changes (such as a TOBT delay or ETA delay) trigger a visual alert to help the ATCO understand that any deviation from the initial plan have been taken into account. As illustrated in Figure 10, a label appears above the strip, displaying the previous time in gray color. The new time is displayed in orange color. This ensures that the ATCO is aware of the change and does not retain outdated information. Once clicked to acknowledge the update, the label disappears. Similarly, if a position change occurs (such as a holding point change or parking stand reassignment) while the flight/strip is already integrated, a label appears below the strip. The previous position is displayed in gray, while the new position is highlighted in orange. This ensures that the ATCO is informed of the modification and does not act based on outdated data. Once clicked by the ATCO to acknowledge the update, the label disappears.

KLM538	M	09:00		
		09:10	>	09:27
		A09		T11

KLM538	M	09:00	09:17	
		A09	>	T10
				T11

Figure 10 : modified strips: (left) the TOBT has been delayed of 10 minutes, (right) the holding point at the runway has been changed to T10.

3.2.3 Timeline presenting the cross-check situations

We assumed that the automation will continuously calculates conflict-free routing for all aircraft over 20 minutes. To enhance safety of operation and support focus on most important situations, we added an adjustable minimum separation rule, which raises a cross-check situation if two or more aircraft are predicted to come closer than the separation threshold. This has been suggested and explored with several ATCOs during our workshops.

A timeline at the bottom of the supervision interface displays all detected cross-checks, as illustrated in Figure 11. The current time is displayed at the start of the timeline and a time window of next 15 minutes is displayed. Each cross-check is positioned at the predicted time at which the spatial distance between two aircraft would be the shortest. To foster attention on cross-check situations, 60 seconds before the computed occurrence time, the strips of the involved aircraft will shift to "Human-Automation Cooperation" encouraging the ATCO to monitor the situation closely. 30 seconds after the occurrence, the strips return to "AI-Controlled".

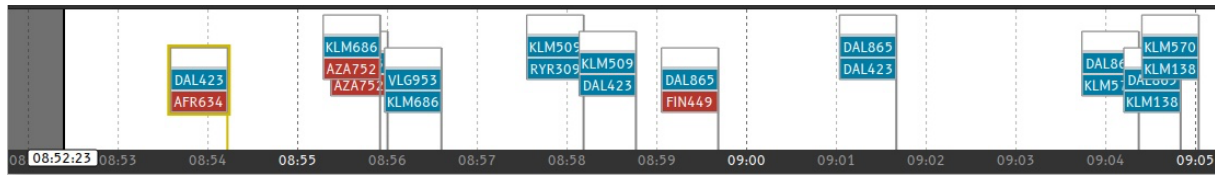


Figure 11: Timeline of the supervision area presenting raised cross-checks in the next 15 minutes.

Each cross-check is represented by a panel showing the location (holding point, taxiway, parking, etc.) and a list of corresponding flights sorted by priority for each cross-check. The order indicates which aircraft has the right of way. The top aircraft has the priority over the bottom ones. Conversely, aircraft on the bottom must give way to top aircrafts. The ATCO can modify priorities by dragging callsigns within the panel. The automation will then recalculate routes accordingly.

3.3 Inspection Interface

Before validating an automation plan for an aircraft, ATCOs can inspect and adjust plan details using the inspection interface presented in Figure 12. It allows ATCOs to increase situation awareness by providing them with tools to assess spatial and temporal plan information computed by the automation. The inspection interface consists of two main areas: The inspection radar (Figure 12 top) that displays aircraft routes and planned events (e.g., coupling to a towing tug, engine start, holding positions) and; the inspection timeline (Figure 12 bottom) that presents the same events in a chronological format. ATCOs 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 and compare over time the selected aircraft route with the other aircraft routes on the taxiways. Exploring by time control allows the ATCOs to improve their awareness of the airport traffic by investigating taxiing plans and aircraft movements dynamically.

The inspection interface displays detailed data about the current selection, which consists of one or multiple aircraft. This feature facilitates rapid supervision by allowing the immediate flight's route visualization on the map, the route start and end times on the timeline, and planned actions such as waiting points, tug coupling and decoupling, along with their positions, times, and durations. When the ATCO selects a cross-check on the global supervision interface, it is also automatically displayed in the detailed inspection interface, and all relevant flights are selected across both interfaces. In addition, the ATCO can add aircraft to the current selection directly from the detailed inspection interface by clicking on the track or label in the radar image (Figure 12). The selection can also be cleared by double-clicking on the background of the interface.



Figure 12: Inspection interface with spatial view at the top and temporal view at the bottom. For selected flights, the inspection displays the planned routes, coupling or decoupling areas, stops or slower motions as well as cross-checks or priorities to support situation awareness from the ATCO.

3.3.1 Inspection radar

The inspection radar allows to explore the future traffic. To differentiate the real-time radar display on the A-SMGCS and the inspection radar display on the inspection interface, a darker shade was used for the inspection radar background. The representations of aircraft, tugs or helicopters are consistent in both radars, and flight labels follow the same color scheme: blue for departures, red for arrivals, and green for tugs. The inspection radar allows multiple vehicles to be selected simultaneously. When selected, labels display the predicted future speed as illustrated in Figure 13. Additionally, the automation computed flight path is displayed: blue for departures, red for arrivals and green for towing vehicles.

To visually separate selected aircraft from non-selected ones, the interface uses different levels of opacities. The selected aircraft and their routes are more opaque and visible than the other aircraft. This is meant to enhance inspection of the selection while remaining situational awareness of other traffic. This design ensures the ATCO can build a comprehensive understanding of the predicted future situation, preventing decisions based on an incomplete view of AI forecasts.



Figure 13: (left) Selected flight in the foreground with its route behind it, (right) not selected flight in the background

Graphical automation language

To support immediate understanding of automation's operational plans, we also propose a domain specific graphical language (DSGL) [1], illustrated in Figure 12 and Figure 14 to support immediate understanding of automation's operational plans. The DSGL uses symbols on the aircraft routes or on the aircraft tracks in the inspection timeline view. Relevant instructions were identified during workshops with ATCOs and used to design the DSGL (Figure 14.b):

- "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 towing 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.

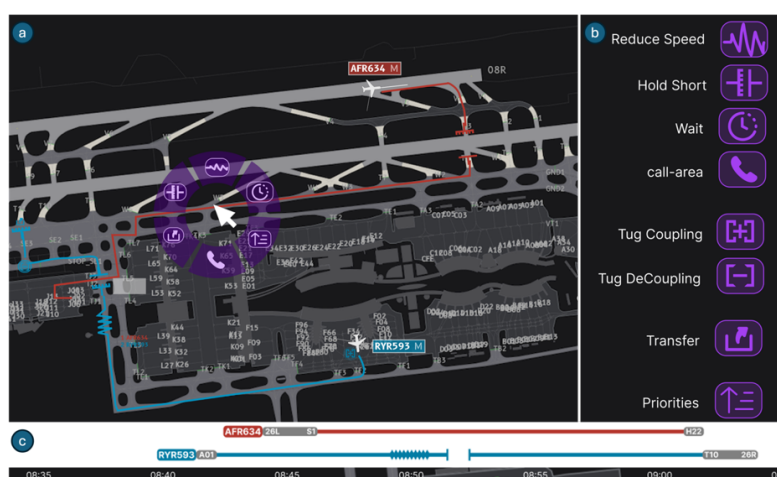


Figure 14: Prototypes of the detailed inspection and advanced surface movement control interface. The domain specific graphical language is displayed over the aircraft trajectories (a) and the timeline (c) to represent operational events such as coupling to uncoupling from a towing tug, stopping to a specific point or reducing speed to enable a priority (b).

ATCOs can adjust priorities and impose new constraints on the automation within the inspection interface. They can also modify routes. Dragging symbols over aircraft routes, time tracks, or by using a contextual menu over a route specific location amends taxiing regulations, resulting in a new computed plan from the automation.

These graphical instructions provide an intelligible representation of the automation's routing plans. Workshop participants emphasized the importance of the DSSL as it provides immediate understanding of the plan. They appreciated the use of the same language over the aircraft trajectories (Figure 14.a) and the corresponding flight time tracks (Figure 14.c).

Selected Cross-check

When a cross-check is selected in the global supervision interface, a representation of the expected priorities between the two aircraft is displayed as a vertical callsign list, sorted in order of priority as presented in Figure 15. This list is positioned close to routes intersection area. The mechanics of cross-check resolutions in the inspection interface build upon air traffic controllers conflict resolution with priority assignments to aircraft. In our design, the aircraft at the top of the list has the highest priority: the second aircraft must give way to the first.

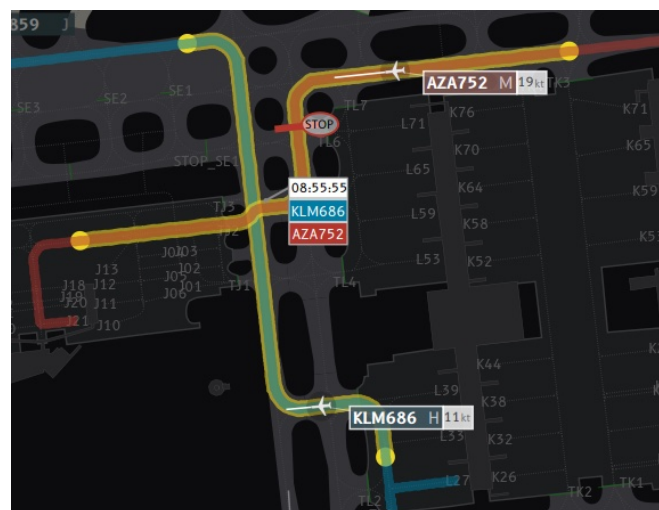


Figure 15: Selected cross-check with panel of strips and yellow segments and handles

If the ATCO wishes to modify the priorities order, callsigns can be simply dragged up or down to increase or decrease the aircraft priority. Once released, the automation recalculates a solution that complies with the new crossing sequence. The color-coding of flights (blue for departures, red for arrivals, and green for tugs) ensures easy identification. A visual link connects the priority information panel to the potential taxiing trajectories intersection on the radar, as shown in Figure 15.

Parts of the routes of aircraft involved in a cross-check are highlighted in yellow, representing the 60 seconds before and 30 seconds after passing the routes intersection. Handles at both ends allow the ATCO to adjust these duration. The handles located before the intersection occurrence are related to a shift from “AI-Controlled” to “Human-Automation Cooperation”, signaling the need for closer supervision. The handles located after the intersection occurrence are related to a shift from “Human-Automation Cooperation” to “AI-Controlled” meaning that enhanced supervision can be resumed.

These adjustments dynamically update the displayed trajectory, ensuring that ATCOs have the necessary flexibility to refine their monitoring parameters and adjust the supervision to the situation at hand or according to their preferences.

3.3.2 Inspection Timeline

The inspection timeline represents similar cross-checks but over time. The tool provides a 20 minutes perspective into the future as illustrated in Figure 16. It displays all currently selected aircraft. The supervisor can select a specific time by dragging the timeline horizontally. A vertical bar marks the selected time.

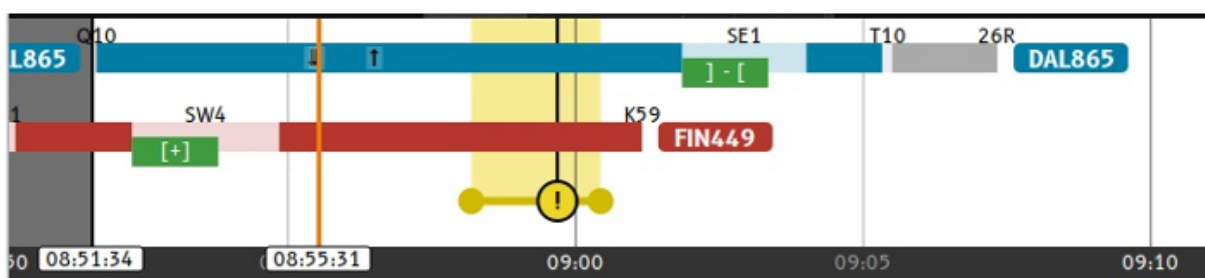


Figure 16: Prototype of the inspection timeline with current time at 08:51:34, selected time at 08:55:31 and a cross-check between 2 flights.

Each selected flight appears in the timeline as a track bounded by the start and the end of taxiing. The flight's callsign is displayed on both sides to ensure it is always visible. Tracks are color-coded: blue for departures and red for arrivals, maintaining consistency with current tools at CDG airport. Each track also contains a list of automation actions, with their corresponding times inferred from their position on the timeline, durations determined by the distance the action is performed, and airport landmarks. Note that if the taxiing time is greater than 20 minutes, the user can then scroll the timeline.

For departing flights, the displayed information may include the departure parking location, any potential holding points (such as terminal exits) with their expected durations, tug coupling and decoupling actions (with tug identifiers), de-icing zones if applicable, the final holding point before runway entry along with its duration, the runway itself, and the moment of transfer from the ATCO to the Tower Controller. Similarly, for arriving flights, the interface shows the landing runway, potential waiting points for airports with runway pair systems (such as CDG), the taxiway exit, tug-related actions if applicable, terminal entry waiting points, and the arrival parking location. The gray parts at the edges of the tracks indicate that the flight is either not yet or no longer under the responsibility of the ATCO.

In addition to these flight details, the interface also displays automation computed regulations such as cross-check priorities. The inspection timeline highlights situations where one vehicle must give way to another, where vehicles must slow down to prevent a potential conflict, or where maintaining a minimum speed is necessary for safety.

When a cross-check is selected, the related strips appear according to their priority level, with the highest priority at the top. Cross-checks are highlighted with a yellow area, visually linking the related aircraft involved in a potential conflict. A vertical bar with an exclamation mark denotes the moment

of the intersection between the two aircraft. We provide similar handles and mechanics as in the inspection radar for the supervisor to manage cross-checks from the inspection timeline as well.

3.4 Integration of automation level in the A-SMGCS view

In this section, we describe the A-SMGCS used to supervise the traffic on the platform and how it integrates with our tools. Figure 17 show a live traffic situation on the interface. Several representations and interactions are available on the A-SMGCS to help optimise the traffic manually by using route suggestions. These are out of scope of this deliverable and are already defined in A-SMGCS specifications, more can be found in AEON D1.2 CONCEPT OF OPERATIONS FINAL VERSION and D.3.2 Supervision HMI delivebrables.

The map background is light to avoid any confusion with the dark background of the inspection radar image displaying future movements.



Figure 17: A-SMGCS used in conjunction with our interfaces.

Figure 17 illustrates the design of the aircraft's labels according to the ATCO responsibility and the automations levels. If a flight is not yet under the ATCO's responsibility, its label remains minimized and highly transparent (Figure 18. left). When the flight is transferred to the ATCO, the label expands, revealing its details. If the ATCO places the strip in the "Human-Automation Cooperation" or "Human-Controlled" column, the label becomes fully opaque (Figure 18. center). Additionally, a dashed yellow outline appears around the radar track, allowing the supervisor to prioritize monitoring these flights. However, if the strip is placed in the "AI-Controlled" column, the label remains partially transparent (Figure 18. right). This visual distinction helps highlight the flights that the ATCO wants to follow and control.



Figure 18: Labels state according to the responsibility and automation levels. Left: not yet in the ATCO's sector. Center: integrated with automation level 1 or 2. Right: integrated with automation level 3 (AI)

4 Scenarios and interactions

This section illustrates how the set of HMIs described in the previous sections enables ATCOs to perform their activities. We present several design scenarios *i.e.* scenarios with the envisioned sequence of interactions, together with descriptions of the actions performed by the ATCOs and reactions from the machine and explanations concerning the intention of the ATCOs. The scenarios are based on the use cases defined in D.3.1 but have been simplified to better illustrate how ATCOs will interact with the interfaces.

4.1 Departing aircraft using a taxibot

This scenario illustrates possible interactions related to UC1: taxibot departure. In this scenario, the ATCO review the automation plan for a departure aircraft and give authority to the automation to clear the aircraft for the routes.

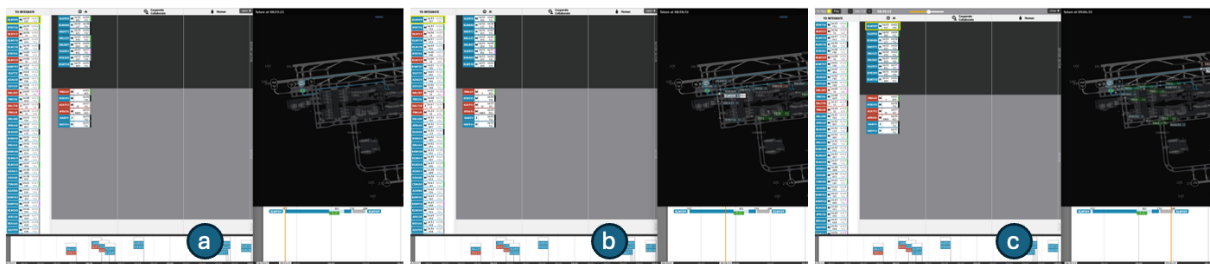


Figure 19: Selecting, inspecting and integrating a departure with taxibot. a) selecting the strip to inspect its route and information. b) inspecting its planned trajectory using the timeline. c) dragging the strip to the AI column to give automation authority.

The ATCO starts by selecting a departing aircraft in the list of flights to be integrated (Figure 19.a). The ATCO then checks the parking and runway information; and inspects the planned route using the DSGL to understand where the aircraft will be attached and detached to the tug. The ATCO then drags the time slider to get an overview of the motion of other aircraft along its planned route (Figure 19.b). Since it appears, ok, the ATCO drags the strip within the AI column to give authority to the automation to handle the aircraft (Figure 19.c).

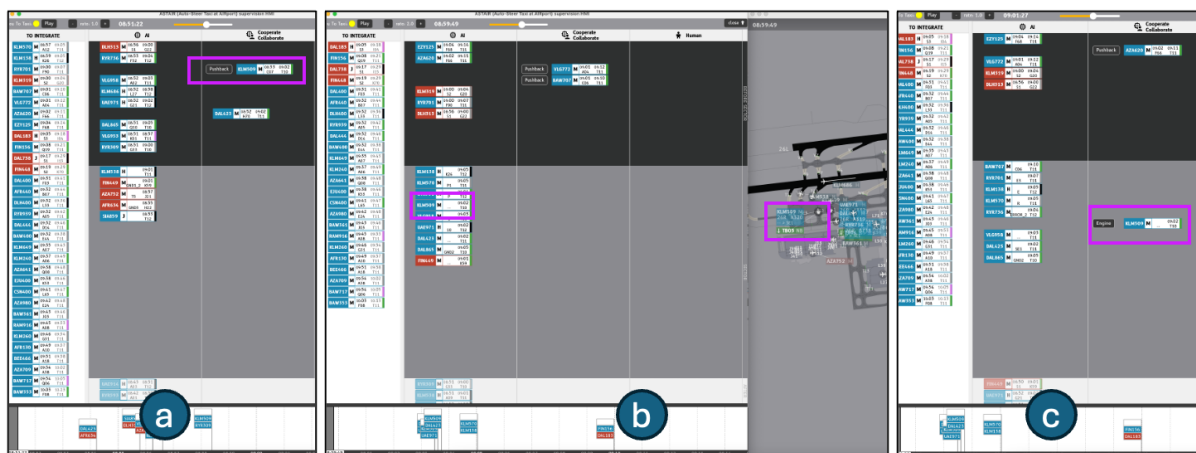


Figure 20: Supervision of the aircraft to startup engines (a), monitor the uncoupling (b) and startup engine (c).

When ready to depart, the aircraft's pilot asks for a push back clearance which animates the strip to the collaboration column and displays a button dedicated to clear the aircraft (Figure 20.a). The ATCO presses it, which animates the strip back to the AI column. The automation gives routing clearances and speed indication to the aircraft. The ATCO can supervise the flight using the A-SMGCS or the supervision interface (Figure 20.b). After uncoupling with the tug, the aircraft's pilot asks a clearance to startup the engines which animates the strip to the collaboration column and displays a button dedicated to clear the aircraft (Figure 20.c). The aircraft then reaches the runway entry point and is transferred to the Tower controller. The strip is moved toward the bottom area of the screen before being removed from the interface.

4.2 Arrival flight without parking

This scenario illustrates possible interactions related to UC3: Arriving traffic without parking. In this scenario, the ATCO can adjust the strategy used by the automation to cope with an arrival without parking.

20'	DAL738	J	09:13	26L	>	I15
	VLG953	M	09:32	K01	>	26R
			09:12			
	DAL183	H	09:11	26L	>	I04

Figure 21: Visual indication of a delay after the strip have been integrated by the ATCO.

The departure flight VLG953, which has already been integrated by the ATCO (placed in the AI-Controlled column), is delayed by 20 minutes due to a passenger issue. A small orange badge with "+20'" appears for two seconds on the left side of the strip (Figure 21). The new TOBT (Target Off-Block Time) of 09:32 is displayed in orange, while a banner below the strip shows the previous TOBT of 09:12 in gray. As a result, this aircraft will occupy parking K01 for additional 20 minutes.



FIN448	M	09:15	26L	>	K01
DLH618	H	09:16	26L	>	J04
UAE457	H	09:18	26L	>	E26
FIN193	H	09:20	26L	>	Q03
UAE971	H	09:21	G21	>	26R
AZA620	M	09:22	F66	>	26R

Figure 22: Visual indication that the allocated parking will not be available.

In the flight integration list, an alert icon appears to the left of the strip for FIN448 as illustrated in Figure 22, an arriving flight originally scheduled to park at K01 at 09:23. The background of parking K01 turns orange, indicating a parking stand conflict.

The ATCO selects the arriving FIN448 and moves it into the Human-Automation Cooperation/Collaboration column. Since no parking spot is available, they have three options to manage the arrival: 1) Taxi slowly to absorb the delay., 2) Hold the flight until K01 becomes available. 3) Change the parking assignment.

To change the parking, the ATCO selects the parking number and chooses another one within a list. Once a parking is selected the previous parking is displayed in light gray while the new one is displayed in Orange as illustrated in Figure 23. Once the data is filled, the automation will use that information to update the automation using this input as a new constraint.

FIN448	M	09:15	26L	>	K13
					K01

Figure 23: Arrival strip with an updated parking from K01 (light grey) to a new one, K13 (in orange).

To hold the flight, the ATCO can however the strip to have "+" button appearing between the two columns representing the beginning and end of taxiing. Clicking this button opens a menu with two options as visible in Figure 24:

- Wait on holding point: The ATCO selects a specific holding point on the airport map.
- Slow on taxiway: The aircraft is instructed to reduce its taxi speed.

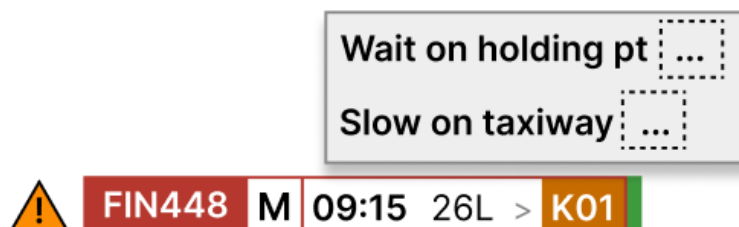


Figure 24: Selecting a slowing method to reach the unavailable parking.

The chosen solution appears between the two columns and is transmitted to the automation, which then recalculates a new taxiing plan that incorporates the delay constraint for FIN448's arrival.

4.3 Creating a cross-check

This scenario illustrates possible interactions to support ATCOs creating a cross-check in addition to the ones computed by the automation to be able to monitor more efficiently a situation during ground movements.

The ATCO selects two strips and drags them downward towards the timeline. When dragging, a ghost image follows the mouse position as illustrated in Figure 25. The ATCO releases the ghost copies of the selected strips above the specific time where to create the cross-check.

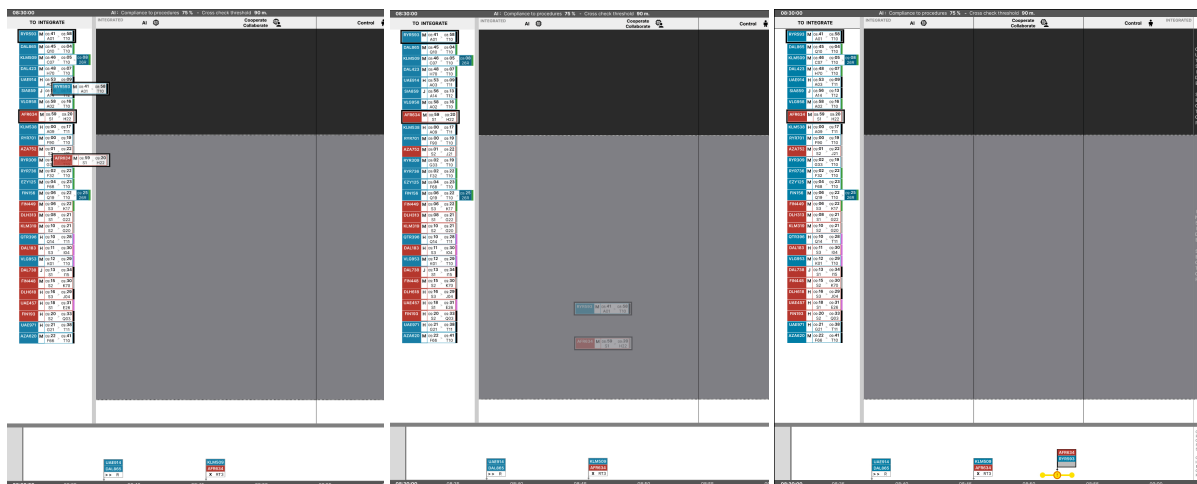


Figure 25: Creating a cross-check. Left) selecting two strips in the list of flights. Center) Dragging them to the timeline. Right) the cross-check with the two aircraft is added to the timeline.

To add a flight to an existing cross-check, the ATCO selects the corresponding strip, drags it down to the timeline, and releases the ghost copy above the existing cross-check. To remove a cross-check, they press, drag it upward, outside the timeline, and then release it.

4.4 Global automation configuration

This scenario illustrates possible interactions related to the UC4: High level taxi strategy tuning.

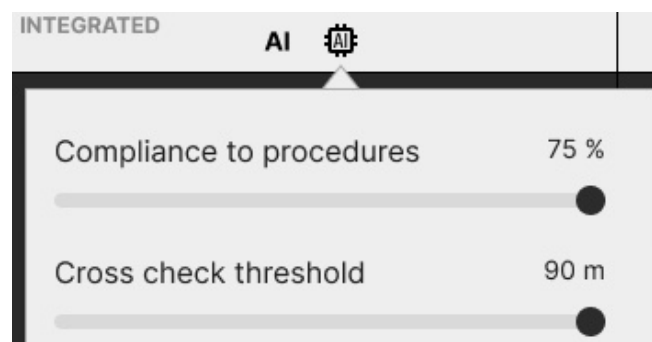


Figure 26: Popup window presenting adjustable parameters for the automation compliance to procedures and the cross-check detection threshold.

The ATCO can click on the header of the AI column to open a popup window containing two adjustable settings as visible in Figure 26:

- **Airport Procedure Compliance Slider:** Moving the first slider to the right forces the AI to strictly follow airport procedures. Moving it to the left gives the AI more freedom in selecting taxi routes.
- **Cross-Check Detection Threshold Slider:** The second slider adjusts the distance threshold for automatic cross-check detection. Figure 27 illustrated the impact of the slider on the list of cross-checks. Lowering the threshold limits detection to only the most critical cross-checks, where aircraft pass very close to each other. Increasing the threshold makes more cross-checks visible, including those with larger spacing between aircraft.

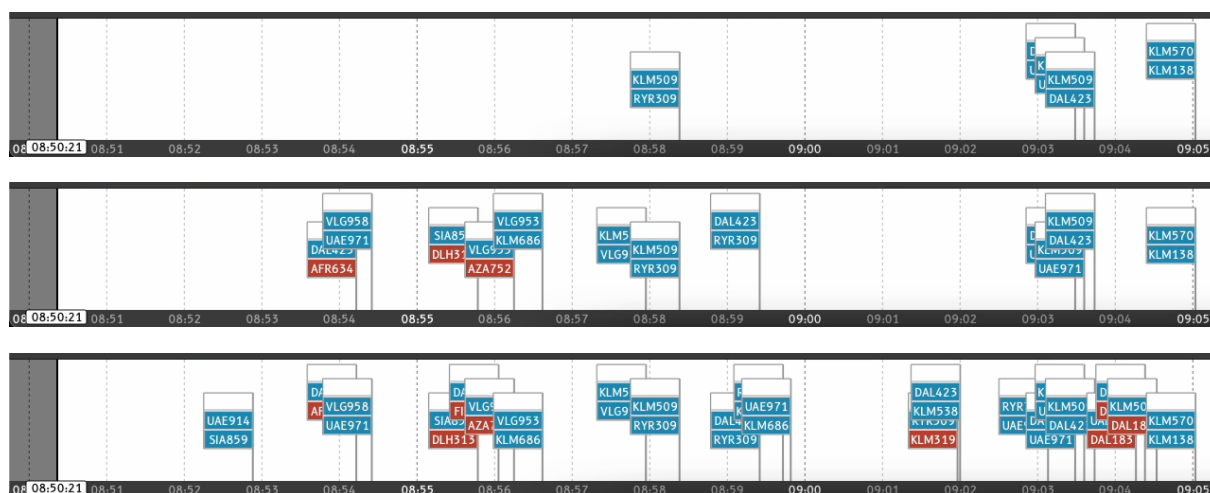


Figure 27: Different list of cross-checks according to the threshold selected.

4.5 Arrival flight with technical issue

This scenario illustrates possible interactions related to UC8: Arriving flight with technical issue.

Upon landing, the pilot of arrival flight AZA752 calls the ATCO via radio to report a technical issue. The ATCO decides to manually control the flight by dragging its strip to the right and dropping it in the "Human Controlled" column as illustrated in Figure 28 left. As a result, the automation no longer has control over this flight and it must be operated by the ATCO and the aircraft icon is highlighted in yellow to indicate manual control within the A-SMGCS as visible in Figure 28 right.

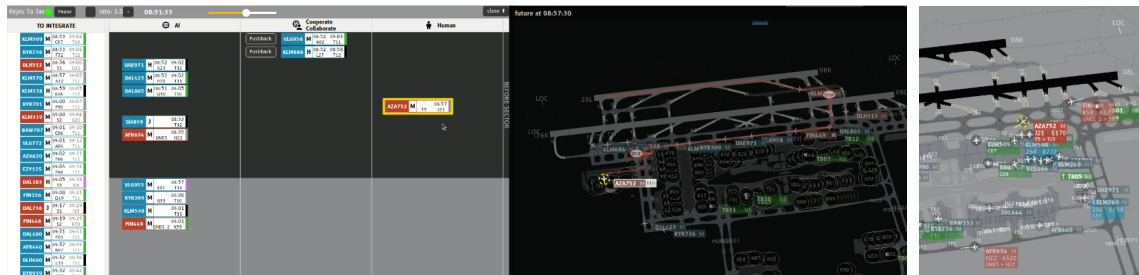


Figure 28: Selecting and adding the corresponding strip within the human controlled column (left). The inspection area displays the planned routes (center) and a yellow circle highlights the aircraft on the A-SMGCS (right).

Figure 29 illustrates how the ATCO can define a new route manually. First, the ATCO selects the aircraft on the A-SMGCS which reveals the current route (previously cleared by the automation) in white. The ATCO then clicks on the nearest available parking spot and lets the automation compute a new route to that location. This new suggested route appears in yellow. The ATCO confirms it by clicking again on the selected parking, turning the route white. The new instructions are automatically transmitted to the aircraft if possible. Finally, the ATCO communicates the updated parking and taxi instructions to the pilot via radio and continues to monitor the aircraft's progress on the real-time radar display.

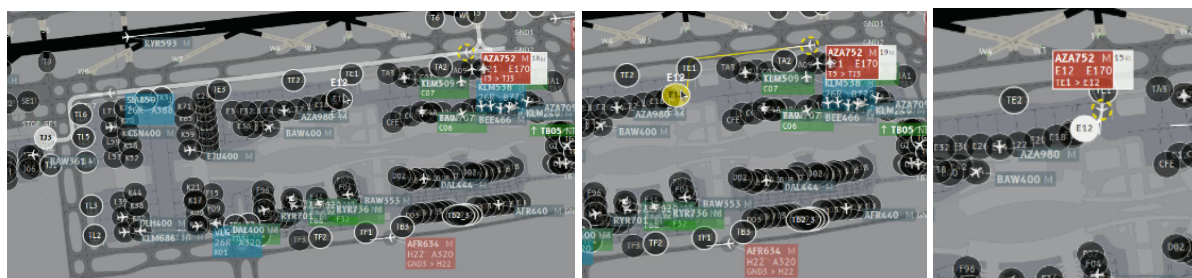


Figure 29: Manually assigning a new route to an aircraft. Left) Selecting the aircraft and visualize the previous route. Center) selecting a new parking and getting a route suggestion. Right) Aircraft reached the new parking.

5 Status and elements

5.1 Deliverable items

Apart from this document, the deliverable includes five videos that demonstrate the following interaction:

- video “1 – Integrating an aircraft, clearing engines and monitoring a cross-check” demonstrates how the ATCO can review the automation plan and integrate the aircraft. It also demonstrates animations and interactions we designed to represent push back-requests as well as during cross-check situations. (https://youtu.be/DPY_MCLSm4Y).
- video “2 – Cross-check creation” demonstrates the interaction to create a cross-check manually. (<https://youtu.be/7S78e-zmzU8>)
- video “3 - Adjusting cross check threshold” demonstrates the interaction and results when adjusting the cross-check threshold. (<https://youtu.be/47Putn3vQR0>).
- video “4 - not available parking” demonstrates how to specify a strategy to the automation to handle a not available parking for an arrival (<https://youtu.be/mLns0XR0iC0>).
- video “5 - Arrival with technical issue” demonstrates how to manually control an aircraft that have a technical issue. (<https://youtu.be/-4IO0SjJtT8>).

5.2 Status of interaction

All the interaction techniques in the scenarios and videos have been developed using the Djnn Framework [4] and the smala language³. The departure and arrival schedule data are realistic and come from CDG airport but have been modified to accommodate our scenarios. The aircraft and tugs taxi routes are generated using a simulation engine including speed profiles. Since the tug allocation and the path planning algorithms are not yet integrated within our prototypes, we have used ad-hoc static allocation plans, performed manual allocations and used the shortest path planning algorithm that provided usable results for demonstration purpose.

Some elements are still missing in what we are envisioning. For instance the DSGL displayed over the planned routes on the inspection map or the timeline must possibly contains other indications such as de-icing or other relevant operational events. We also need to improve the interactions enabling operators to modify the plans by directly interacting with the DSGL such as removing a stop if not necessary anymore or manually adding a priority to handle a possible conflict in emergency situations. Other aspects such as clear indications if the cross-check is created by a human or generated by the automation or systematically adding animation when strips change their location in the global supervision area to enhance change awareness. These elements are currently under design and we are exploring various alternatives.

Most of our interactions have been developed as working prototypes and are being integrated within the validation platform described in D.4.1. Some of them are more complex such as deforming the

³ <http://smala.io/>

trajectory to represent a speed change but should be implemented before the validation or tested as high fidelity prototypes.

6 References

- [1] Conversy, S., Garcia, J., Buisan, G., Cousy, M., Poirier, M., Saporito, N., Taurino, D., Frau, G. and Debattista, J. 2018. Vizir: A Domain-Specific Graphical Language for Authoring and Operating Airport Automations. *Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology* (2018), 261–273.
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- [4] Magnaudet, M., Chatty, S., Conversy, S., Leriche, S., Picard, C. and Prun, D. 2018. Djnn/Smala: A Conceptual Framework and a Language for Interaction-Oriented Programming. *Proc. ACM Hum.-Comput. Interact.* 2, EICS (Jun. 2018), 12:1-12:27. DOI:<https://doi.org/10.1145/3229094>.

7 List of acronyms

The following table reports the acronyms used in this deliverable.

Term	Definition
A-CDM	Airport Collaborative Decision Making
AEON	Advanced Engine Off Navigation
AI	Artificial Intelligence
A-SMGCS	Advanced Surface Movement Guidance and Control System
ASTAIR	Auto Steer Taxi at Airport
ATC	Air Traffic Control
ATCO	Air Traffic Controller
CDG	Paris-Charles de Gaulle Airport
CTOT	Computed Take Off Time
EASA	European Aviation Safety Agency
HCI	Human Computer Interaction
HMI	Human Machine Interface
SESAR	Single European Sky ATM Research
SESAR 3 JU	SESAR 3 Joint Undertaking
TOBT	Target Off Block Time
TSAT	Target Start Up Approval Time
UC	Use Case

Table 1: list of acronyms